Status and Results from Calorimeter Simulations

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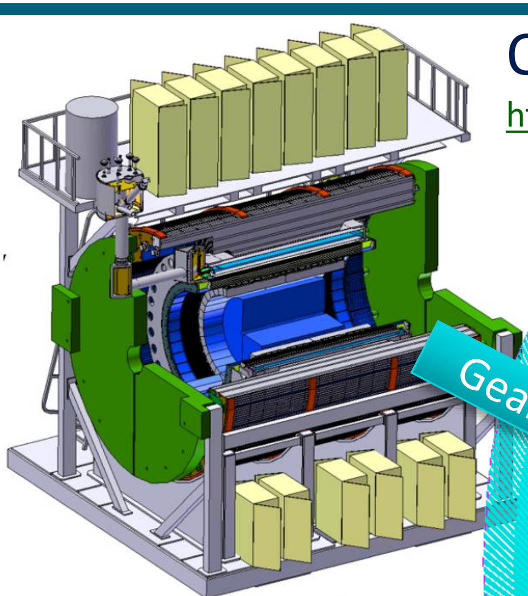
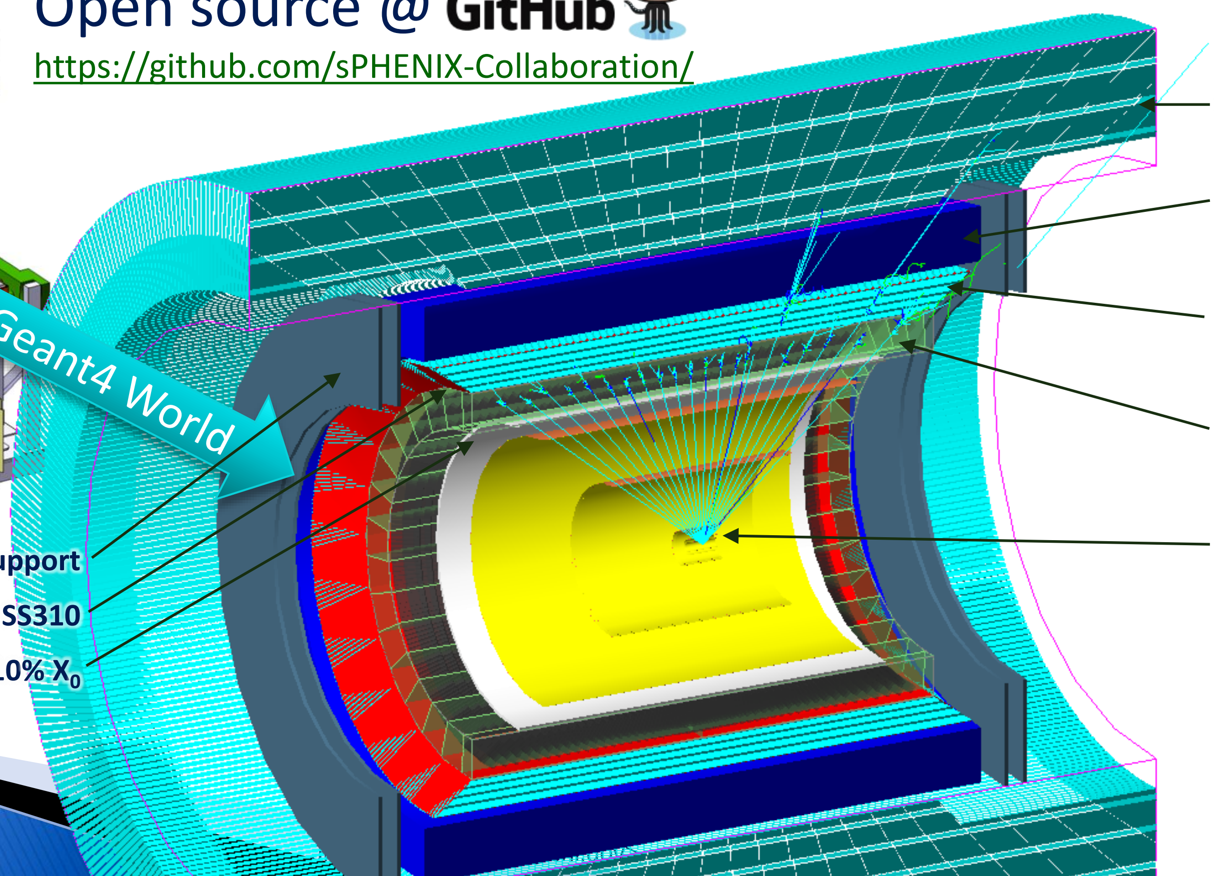
sPHENIX Calorimeters in Geant4

- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 SS-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1.4 X_0 Coil & Cryostat
- Outer hadron calorimeter (outer HCal) : 4 λ_0 SS-Scint. sampling

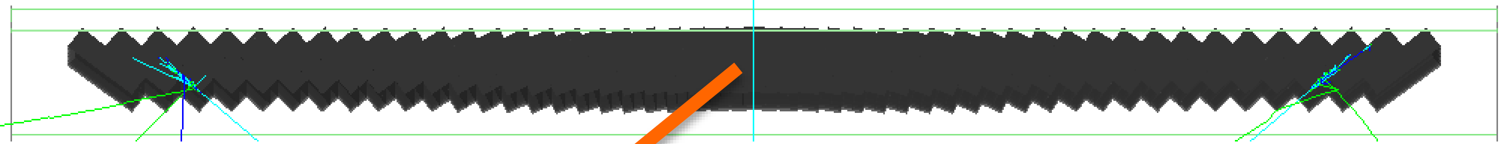
Open source @ GitHub

https://github.com/sPHENIX-Collaboration/

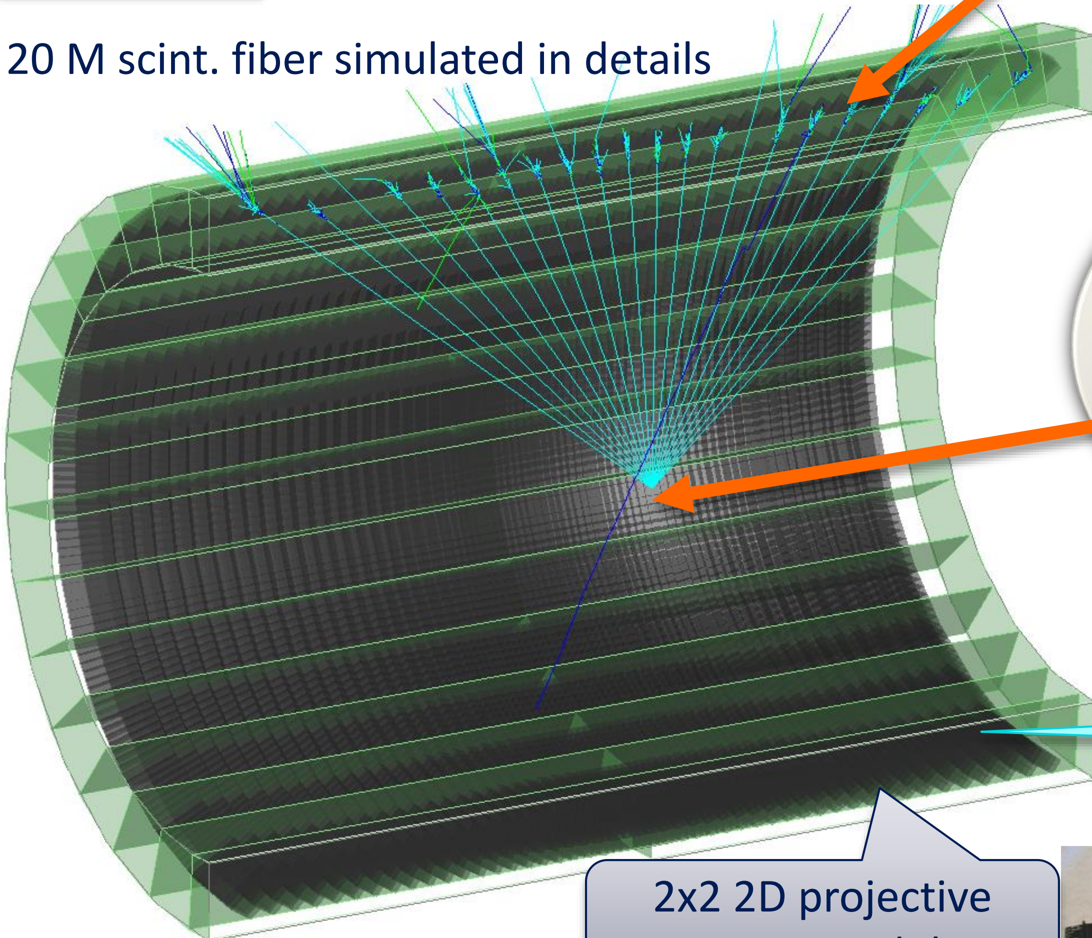




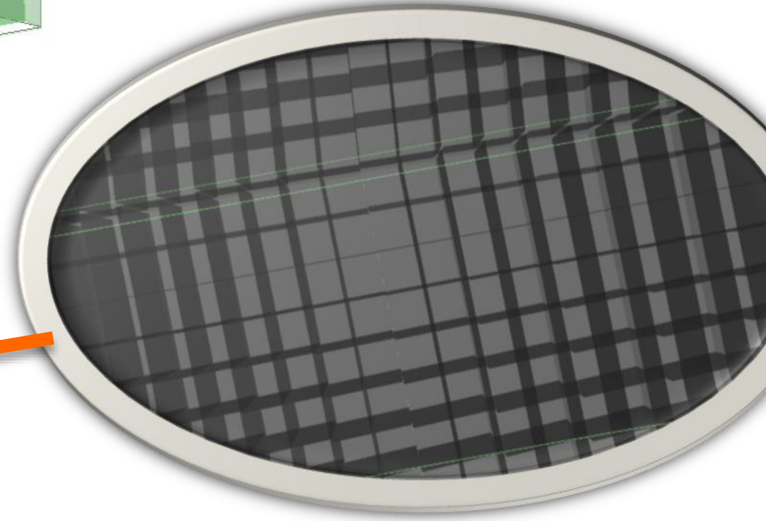
EMCal



20 M scint. fiber simulated in details

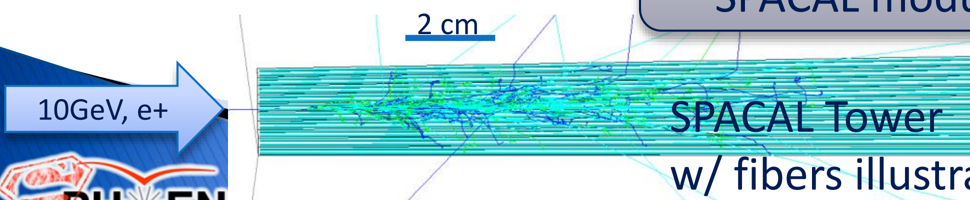


Towers project towards IP



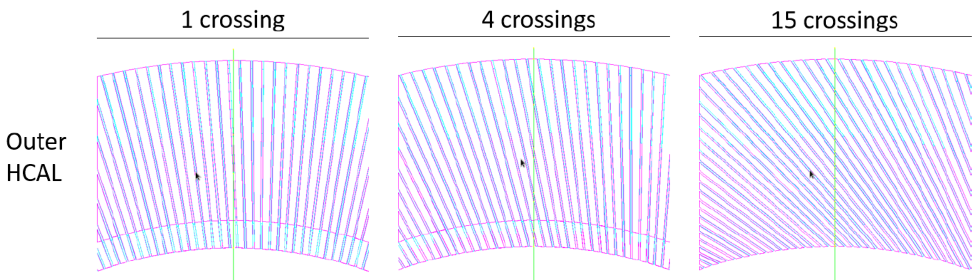
Stainless steel SS310
Support box

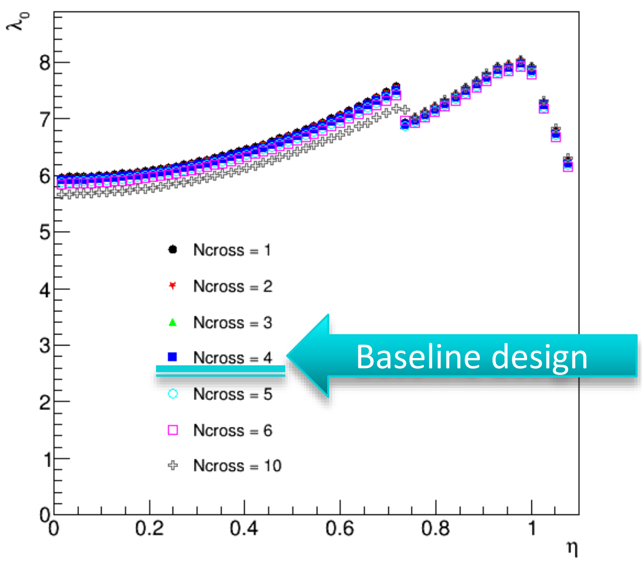
2x2 2D projective
SPACAL modules

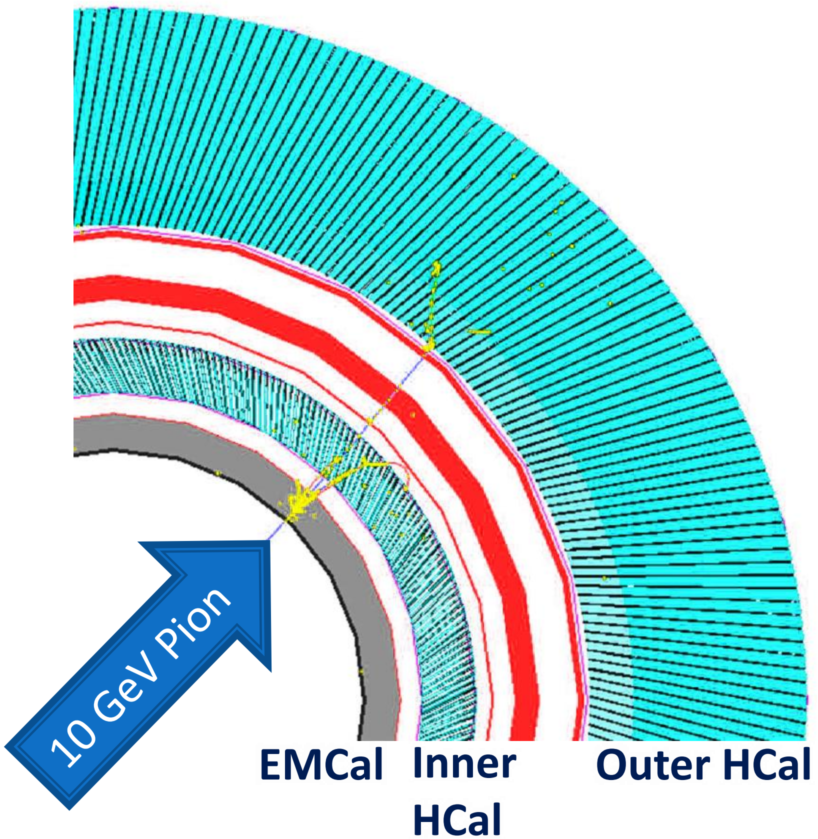


Simulation setup: HCal

- Setup
  - Tilted iron plate with scintillator inserted
  - Detailed magnet field map in detector
  - Variable tilt angle to optimize detector design
- Analysis: Geant4 hit → Scintillation light model → Tower readout → Digitization → Calibrated tower energy → Clustering/Track matching/Forming Jets







That's just the start. Lots of analysis work done, more need to be started:

- Implement more details as R&D/design proceeds
- Verification/tuning of simulation (Beam tests)
- Analysis utilities (Truth association, analysis modules)
- Quantification of detector performance
- Optimizations
- Full Geant4 physics simulation (jet, Upsilons, ...)
- Build the analysis expertise prier to beam

Verification of Simulation: EMCal

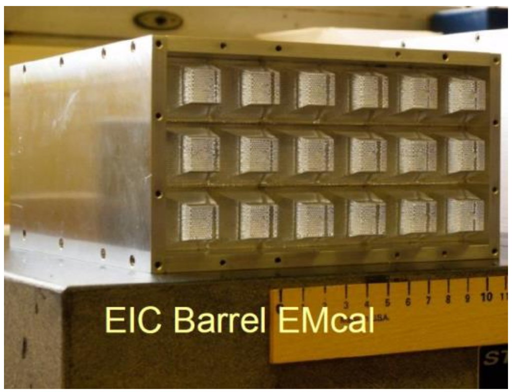
Verification of EMCal simulation using eRD1 2014 data VS sim using sPHENIX Geant4

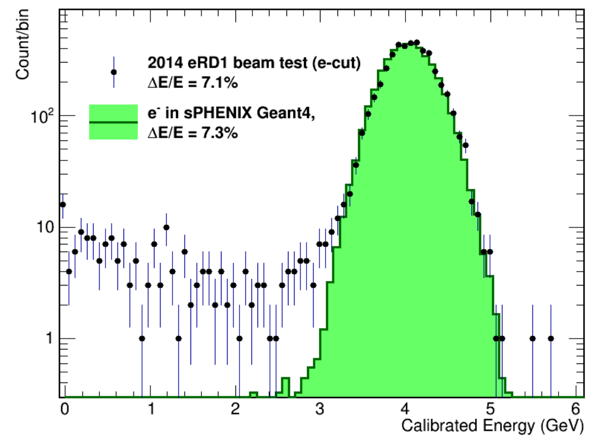
Need this excessive with sPHENIX config, better quantification of hadron tail/tunnel effect

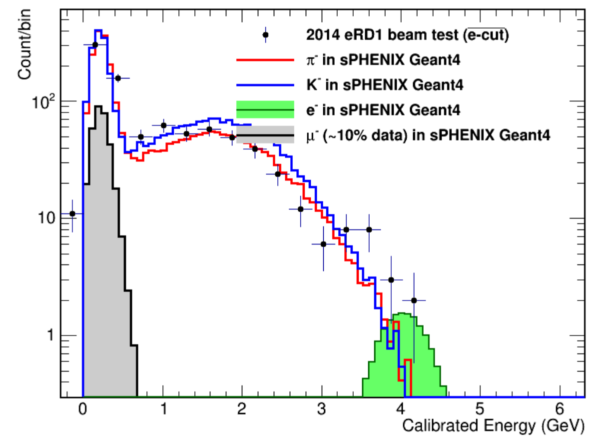
Beam test data reproduced in simulation (4GeV shown, more in pre-CDR)

eRD1 2014 test beam (UCLA)

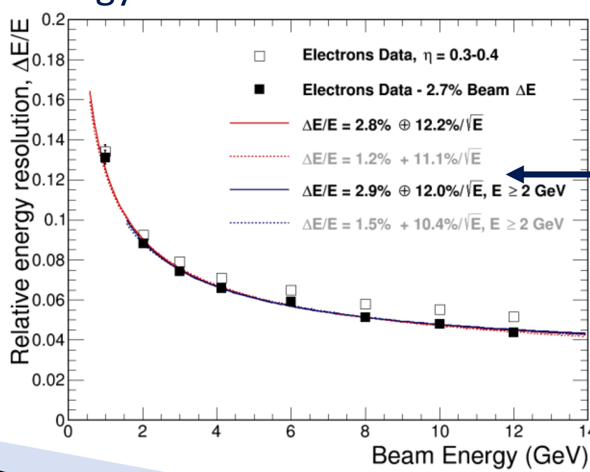
- 1D projective tower in 3x6 block
- slightly different fiber with double cladding



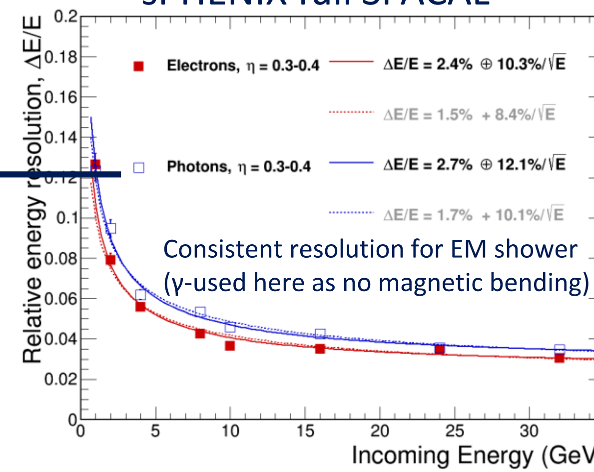




Energy resolution: eRD1 test beam

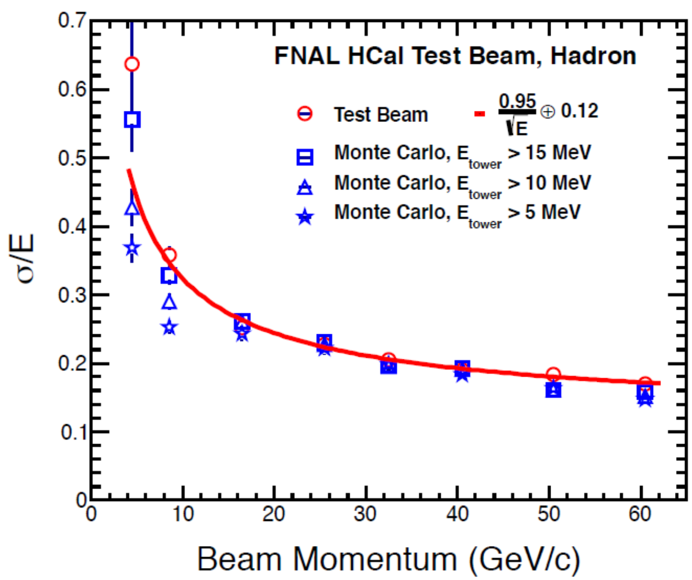


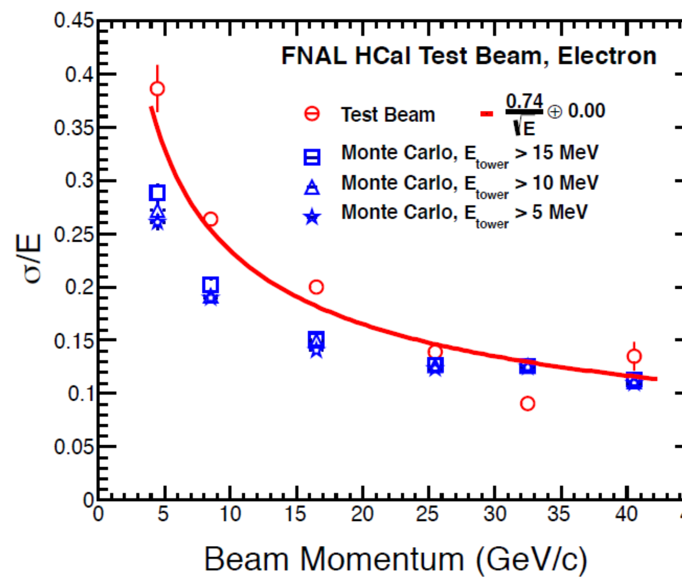
sPHENIX full SPACAL



Verification of Simulation: HCal

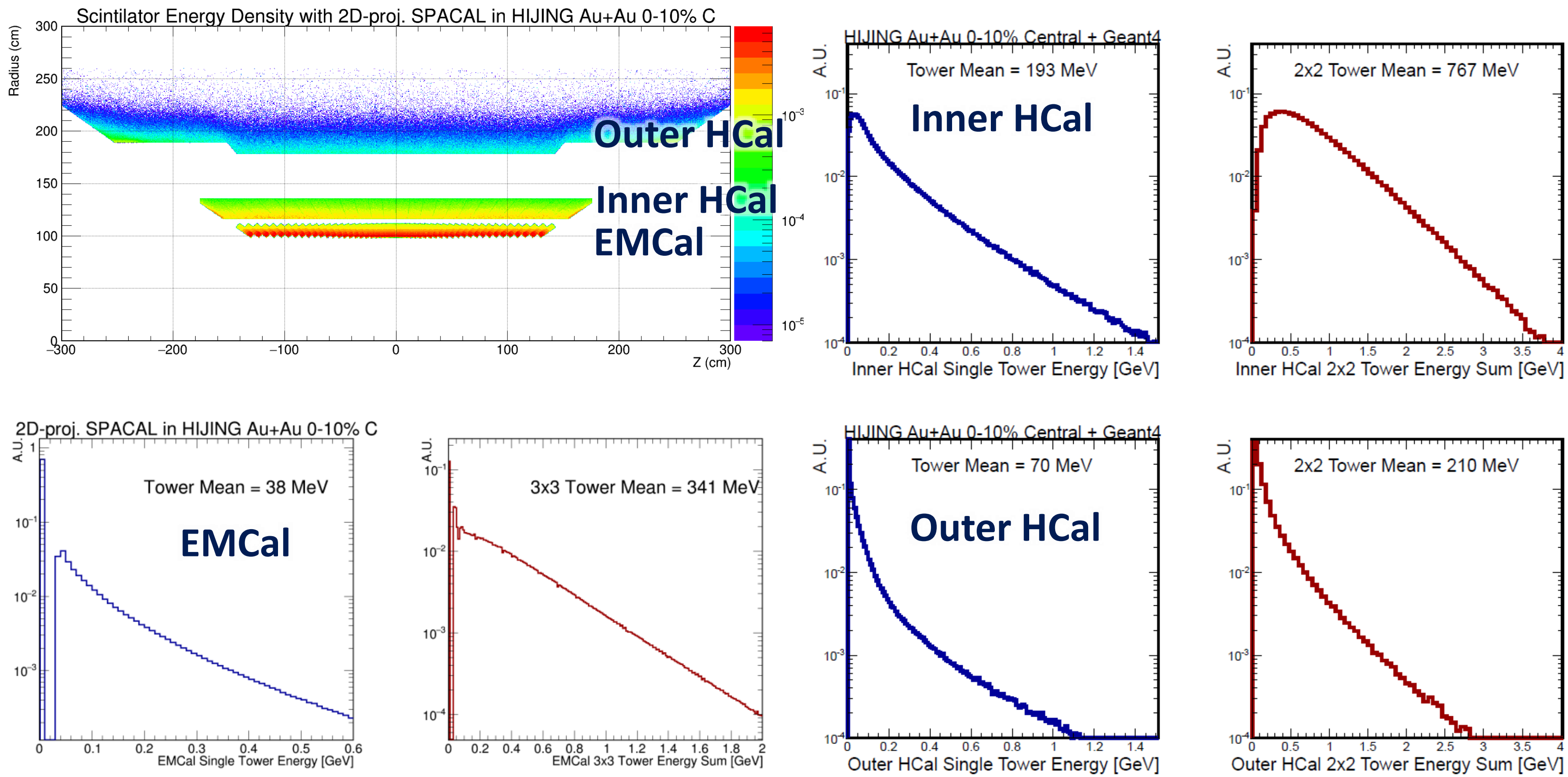
- HCal Simulation tested against Apr 2014 sPHENIX Fermi-lab test beam (HCals alone, v1-design)
- Reasonably reproduced resolution
- New test beam Apr 2016 with full calorimeter system planned (EMCal + Inner Hcal + magnet gap + Outer HCal). Effort on-going with GSU group





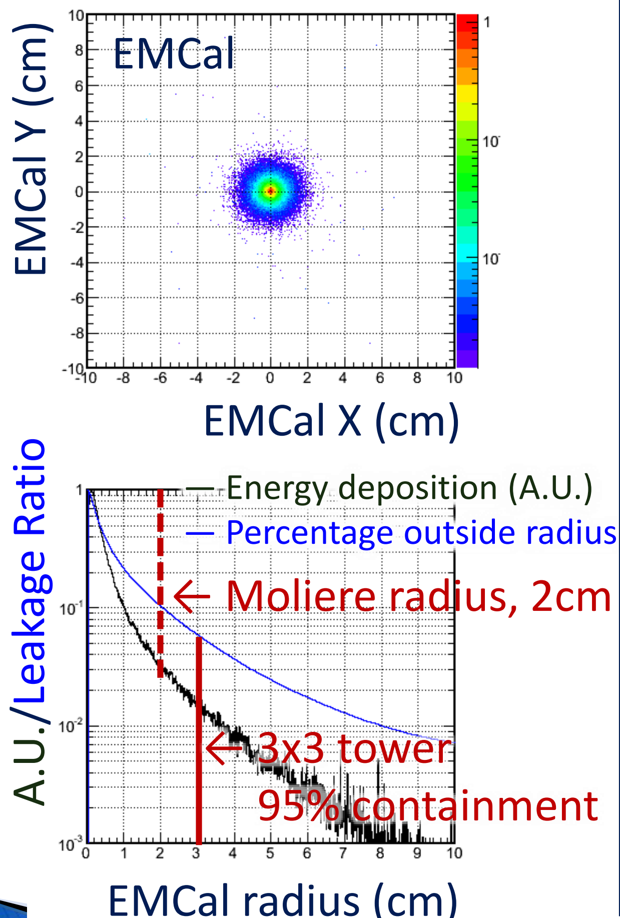
Occupancy in central Au+Au

- sPHENIX are designed to handle large background environment of central AuAu collisions
- Such background is simulated with HIJING → full detector in Geant4 → full analysis chain
- Folded into electron ID and jet projections via embedding

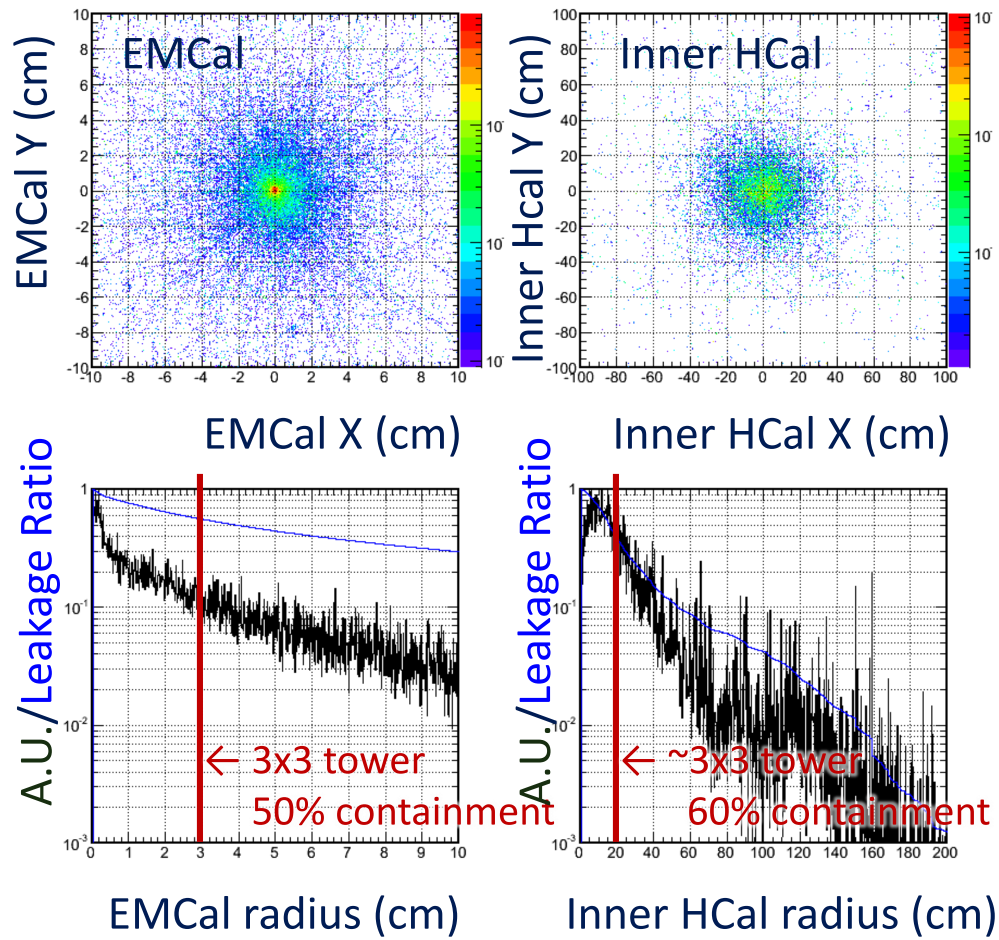


Performance : Single EM showers

4 GeV Electrons



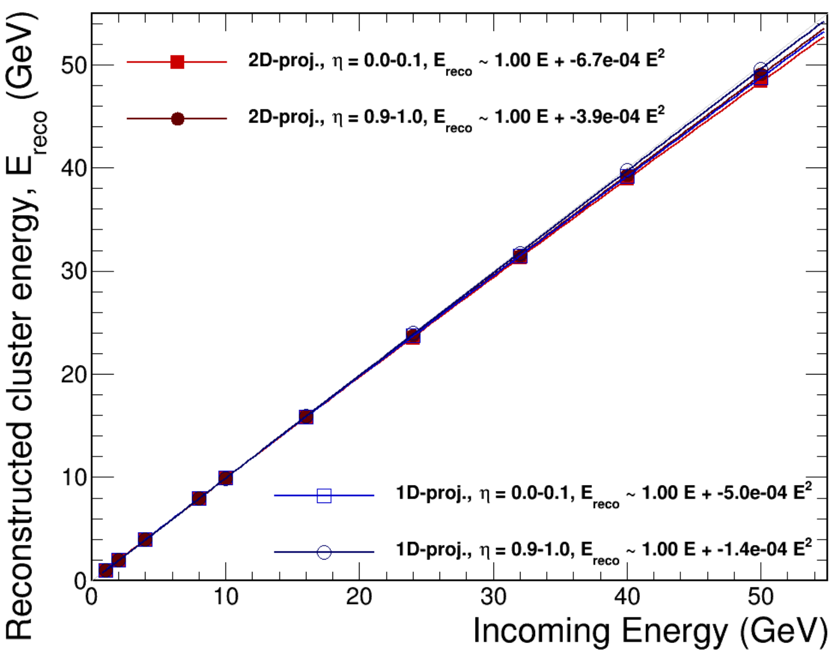
4 GeV Pions, that **passed E/p electron-ID cut**

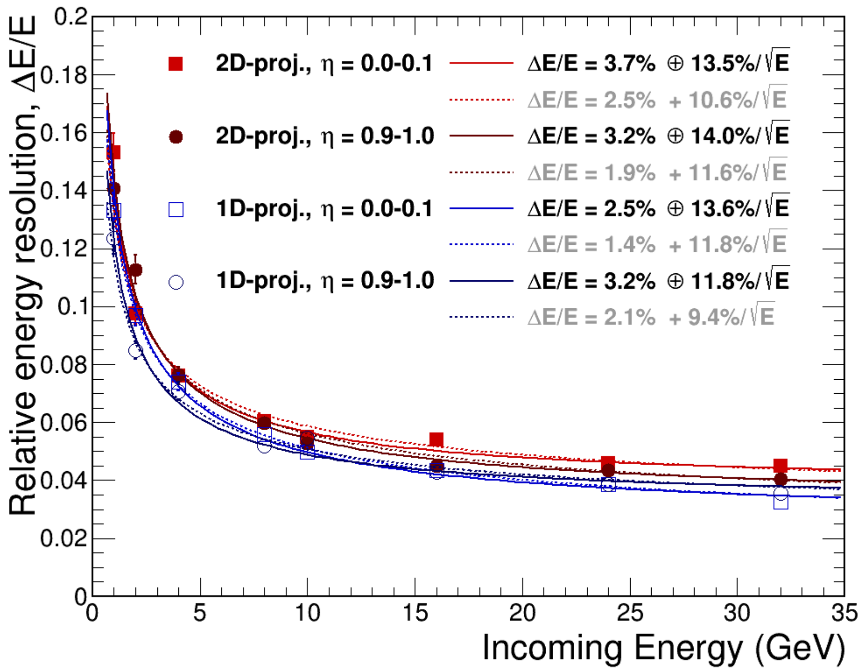


Performance : Single EM showers

- dE/E < 14%/sqrt(E)+4% for photon (fit sPHENIX γ-jet goal)
- dE/E < 12%/sqrt(E) for electrons (fit EIC electron kine. goal)
- Linearity is reasonable

sPHENIX full detector single photon simulation



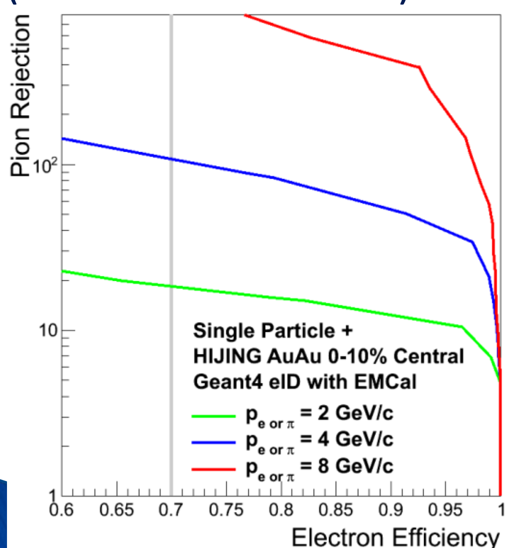


Physics Performance : electron-ID

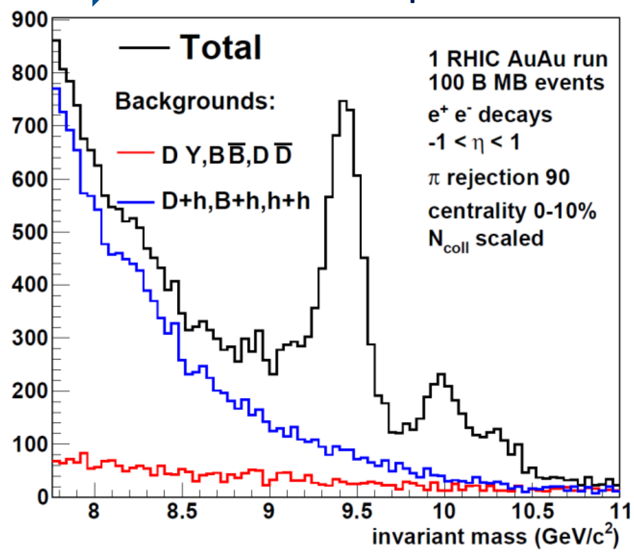
- Critical driving factor for EMCal design:
  Upsilon electron ID & Triggering
- Baseline performance required 90:1 pion rej. @ 70% electron eff.
- Need to be revised again with full detector Geant4 sim with momentum dependency and revised background.

Baseline EMCal performance + Baseline tracker performance → Satisfied the scientific goals

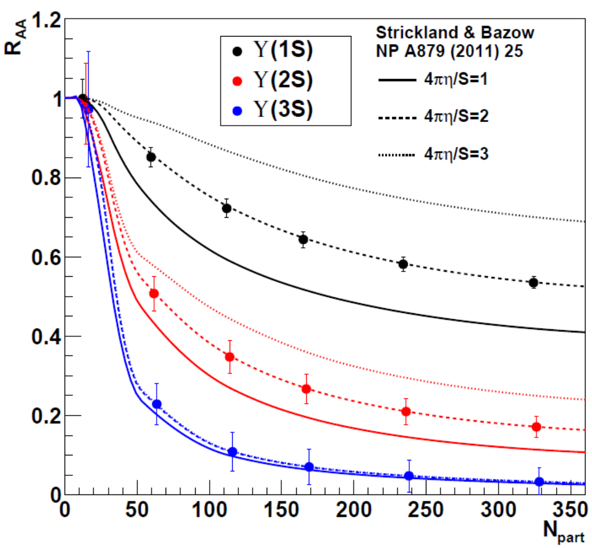
Hadron Rej. ~100:1 @ 4 GeV
(in central AuAu col.)



Δm_{ee} = 100 MeV
Hadron VS Upsilon

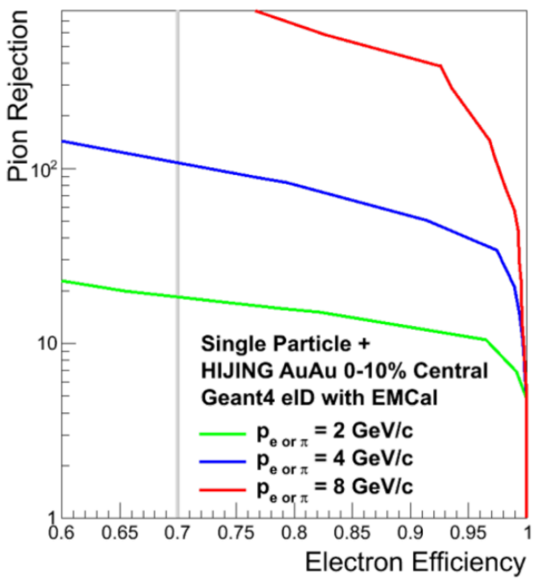


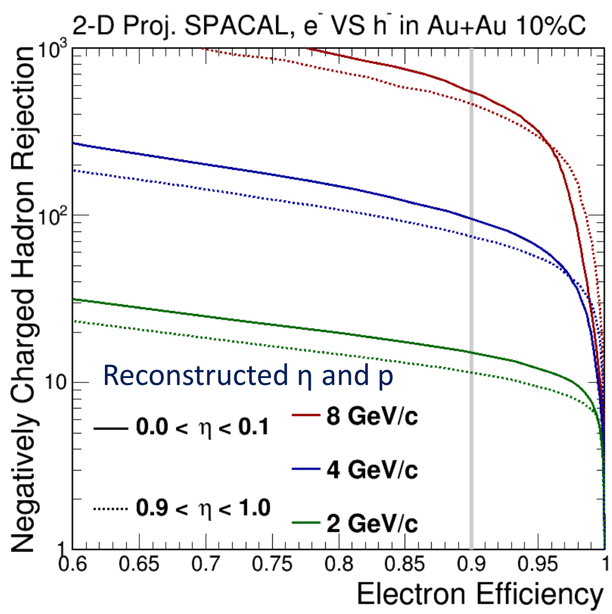
Upsilon R_{AA}

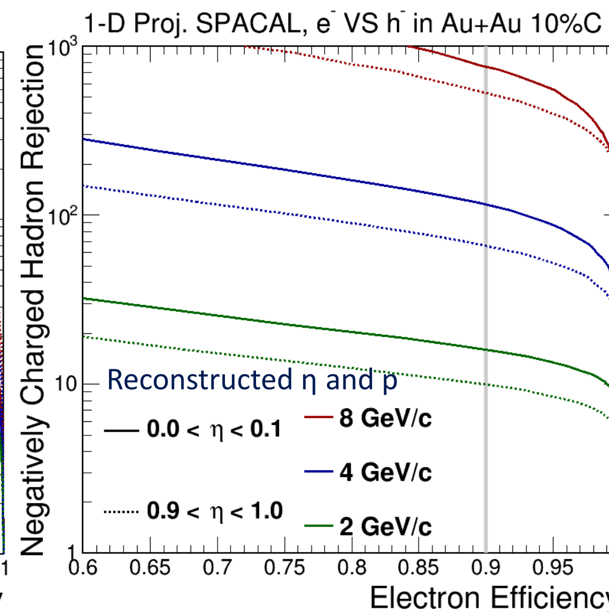


Performance : electron-ID in Au+Au

Updated and more detailed simulation show good safety margin on electron-ID performance on top of the baseline design (as required to reach Upsilon program physics goal)







Baseline performance,
design goals

- Sum all scintillator energy
- 1D SPACAL material with hits grouped into 2D SPACAL towers

2D projective SPACAL

- Updated studies (Preliminary)
- Sum all hadron taking account of hadron ratio
- Full digitization (w/ Birk corrections)
- Full tracking with silicon opt.
- Fully implemented 2D SPACAL (tower/support structure)

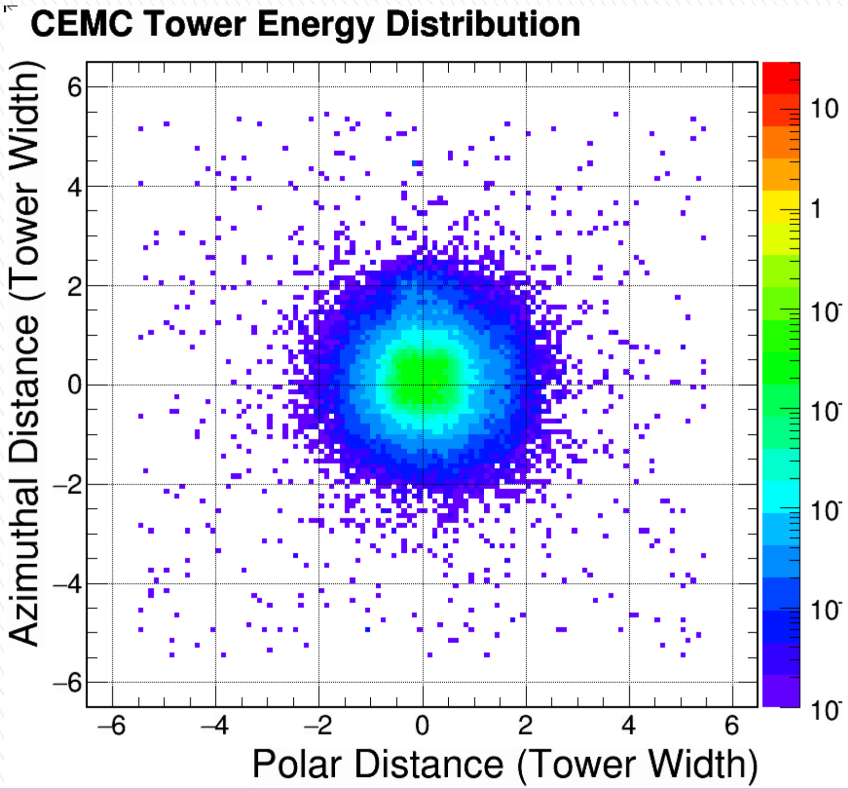
1D projective SPACAL

- Updated studies (Preliminary)
- Sum all hadron taking account of hadron ratio
- Full digitization (w/ Birk corrections)
- Full tracking with silicon opt.
- Ideally towering (no-tower boarder, no enclosure structure)

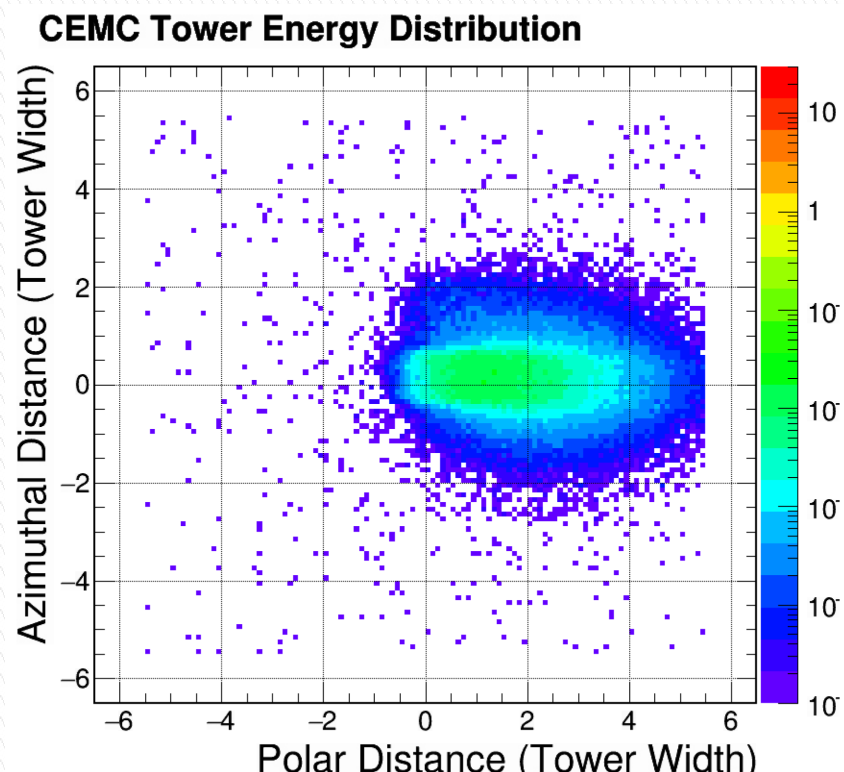
Other considerations in projectivity

- Safety factor to deliver Upsilon physics
- Pi-0 ID and calibration (just starting)
- Soft-lepton tagging in jets (need study)

Single e- 8 GeV shower in 1D/2D proj. SPACAL @ eta=0.9-1.0



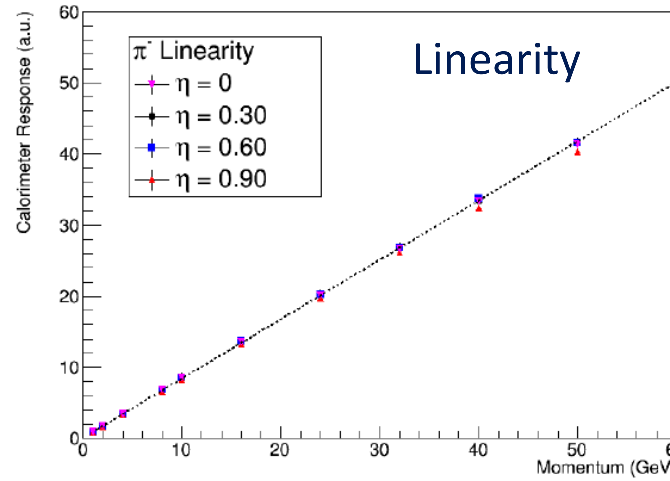
2D projective SPCAL
Average cluster ~8 towers

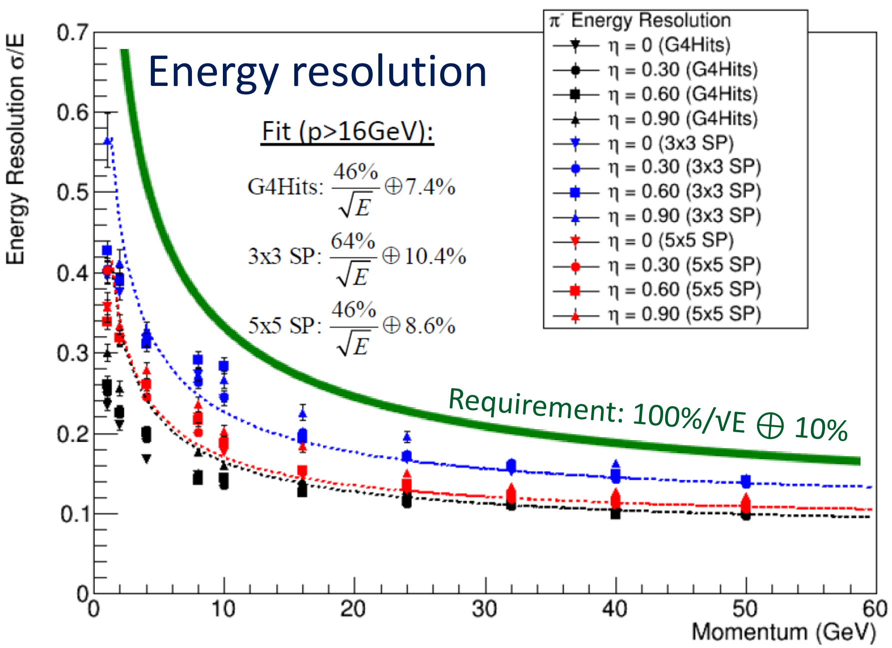


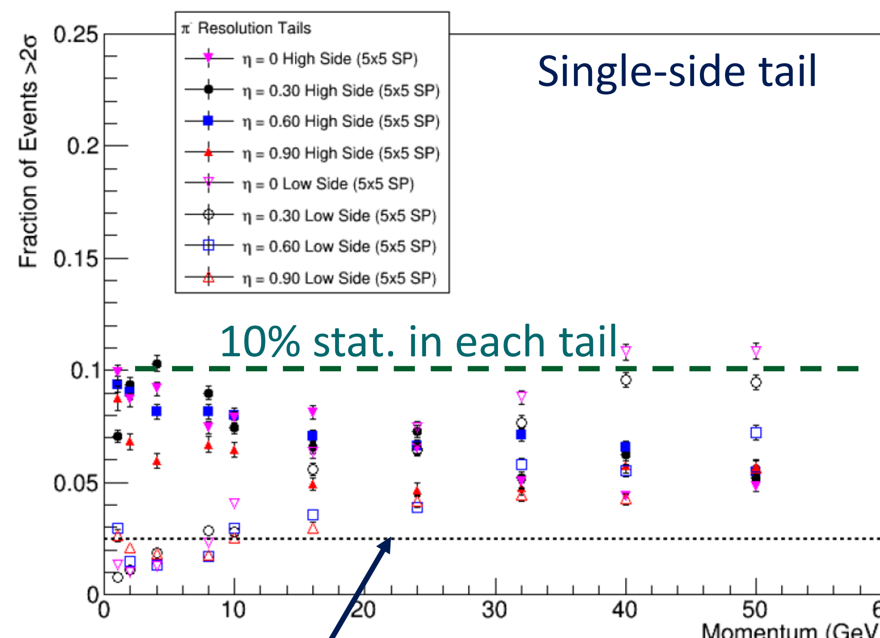
1D projective SPCAL
Average cluster ~12+ towers

Performance : Single Hadron showers

- Single pion shower studied with clusters of digitized towers (3x3 and 5x5 clusters), which is compared with ideal sum of Geant4 hit in scintillator (label G4Hits)
- Energy resolution satisfied design goal.
  Tails <= 10%
- Refinement underway: time cut-off and light collection variations



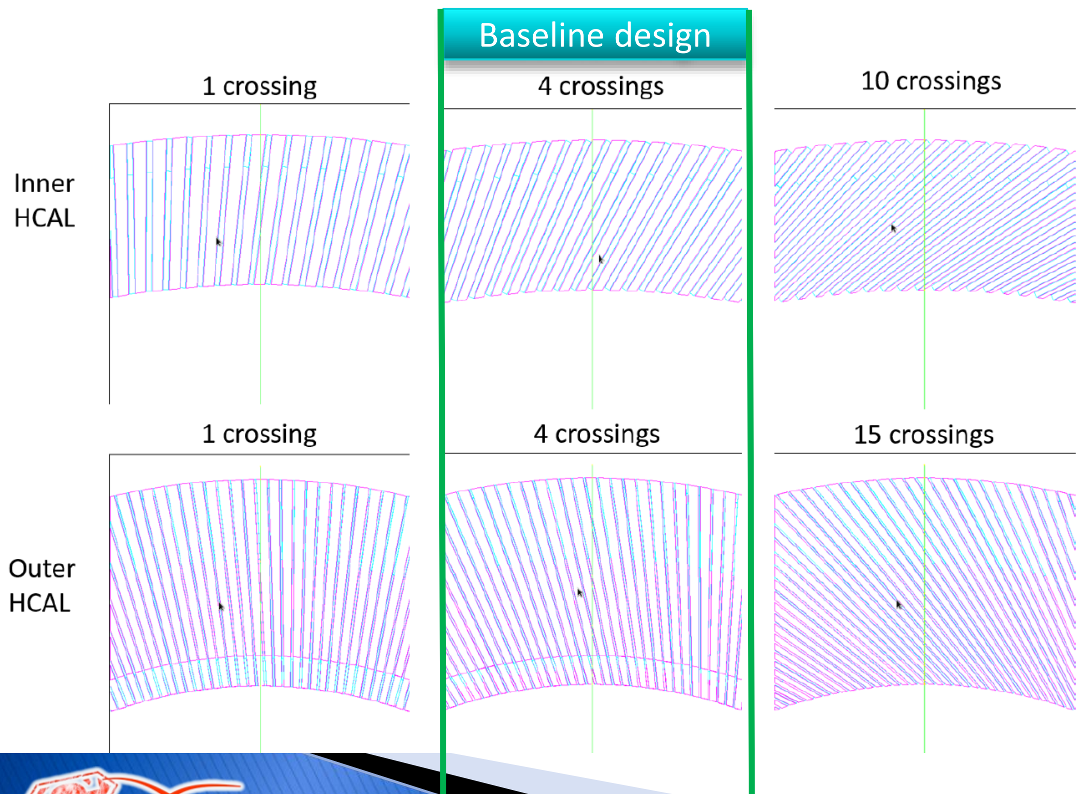


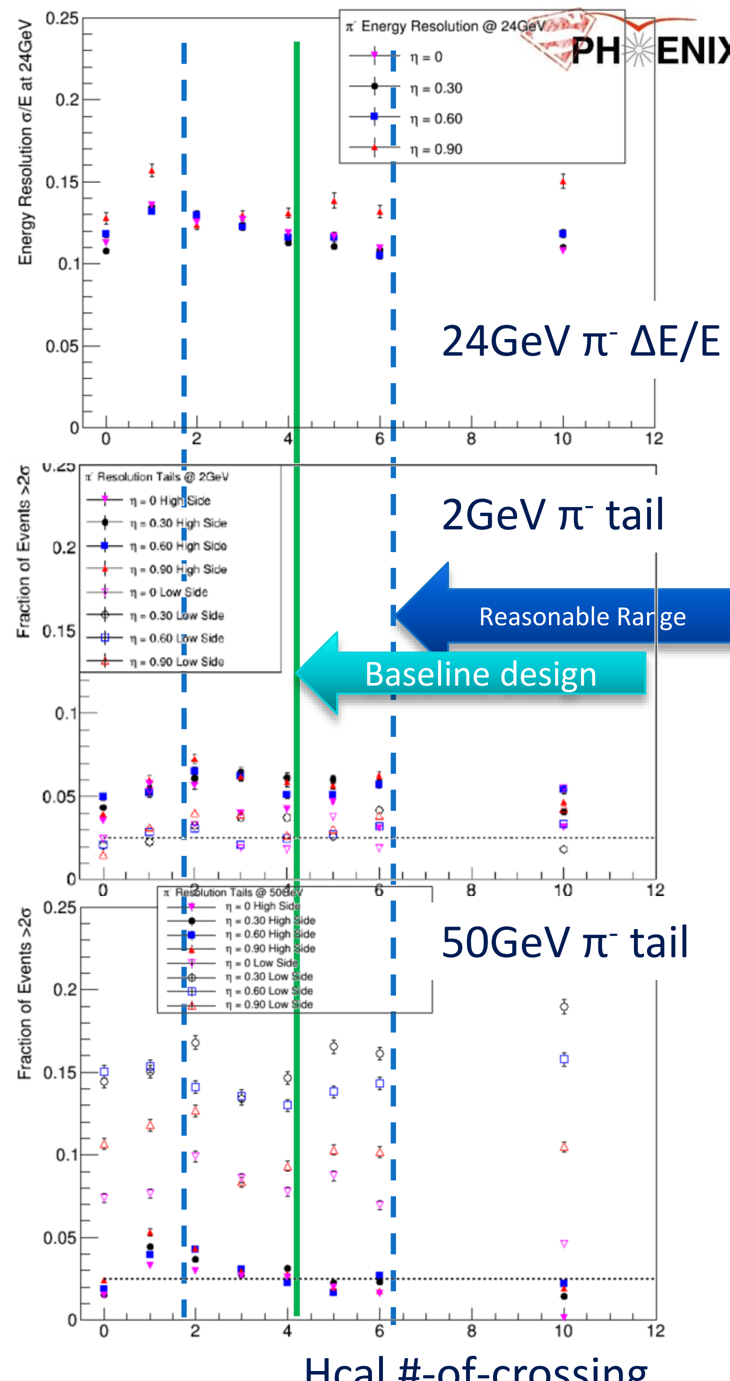


2.5% stat. in tails as expected from Gauss shape

Tilt angle optimization

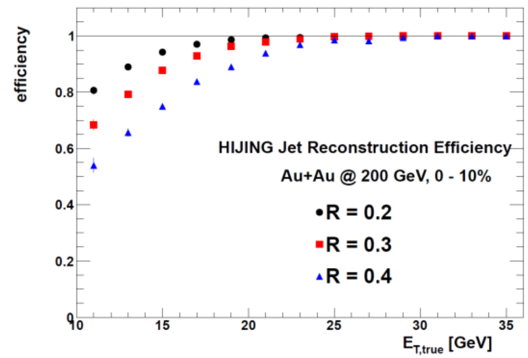
- Performance not a strong function of tilt angle of Hcal iron plates
- Baseline design (4-crossing tilt angle) seems a reasonable choice
- What happen to jet and other observables?

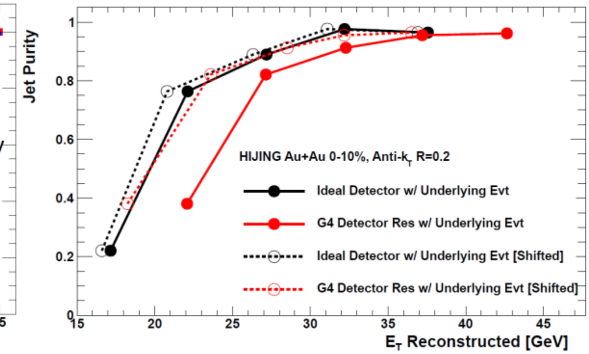


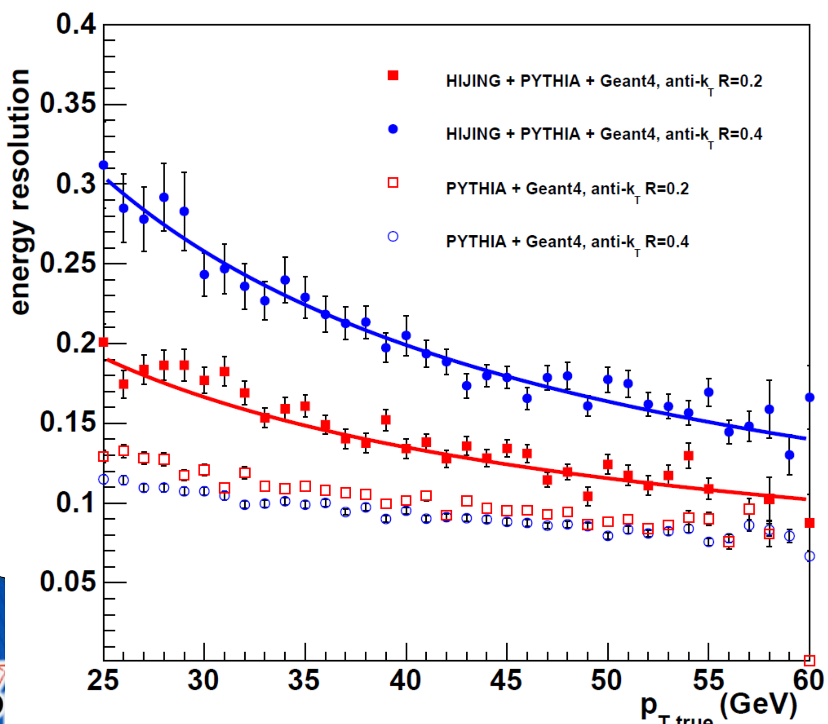


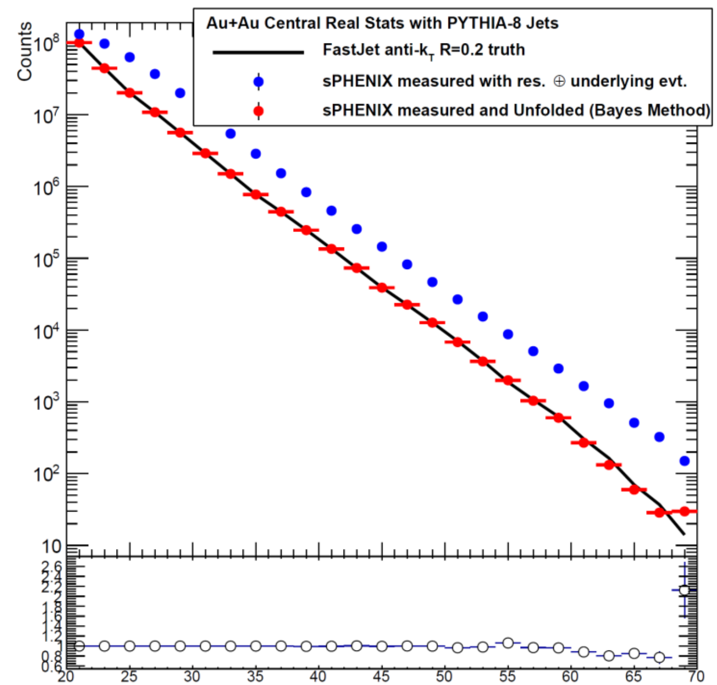
Performance : Jets in central Au+Au

- Algorithm developed based on ATLAS and CMS heavy ion experience
- Good efficiency and purity
- Resolution/tails fit for unfolding jet spectrum
- Need to be updated as detector design/performance evolves



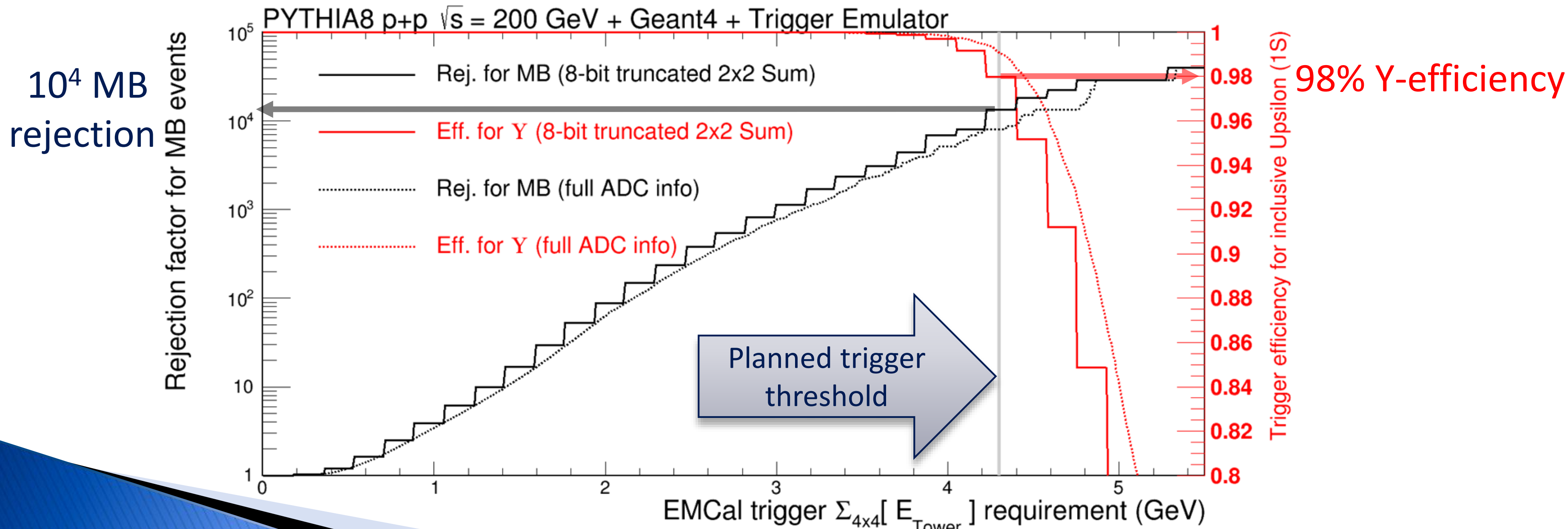






Trigger Performance

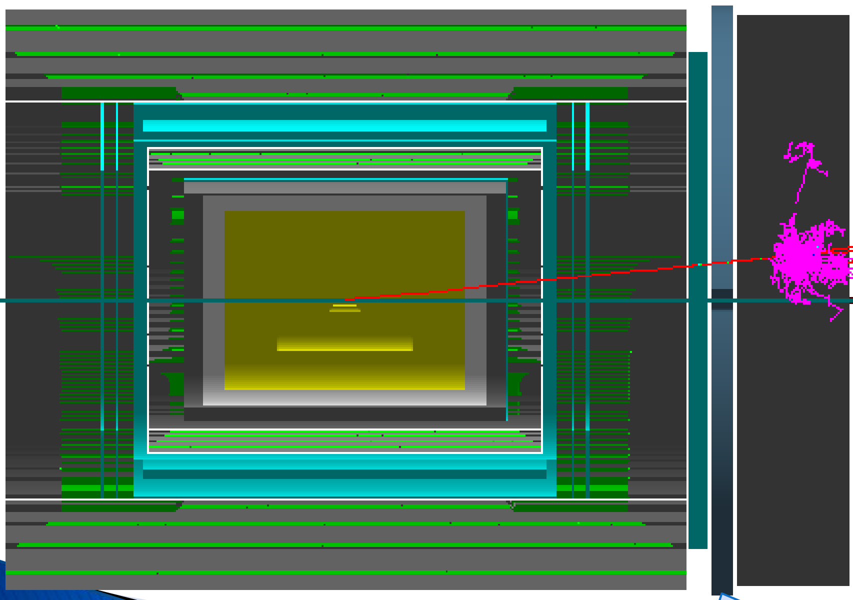
- Most challenging is trigger in pp for rare Upsilon signal
  - Simulated in trigger emulator with truncated ADC bits
  - > 5000:1 rejection with 98% Upsilon efficiency, fit Upsilon in the PHENIX DAQ bandwidth
- Jets trigger needed to be updated too



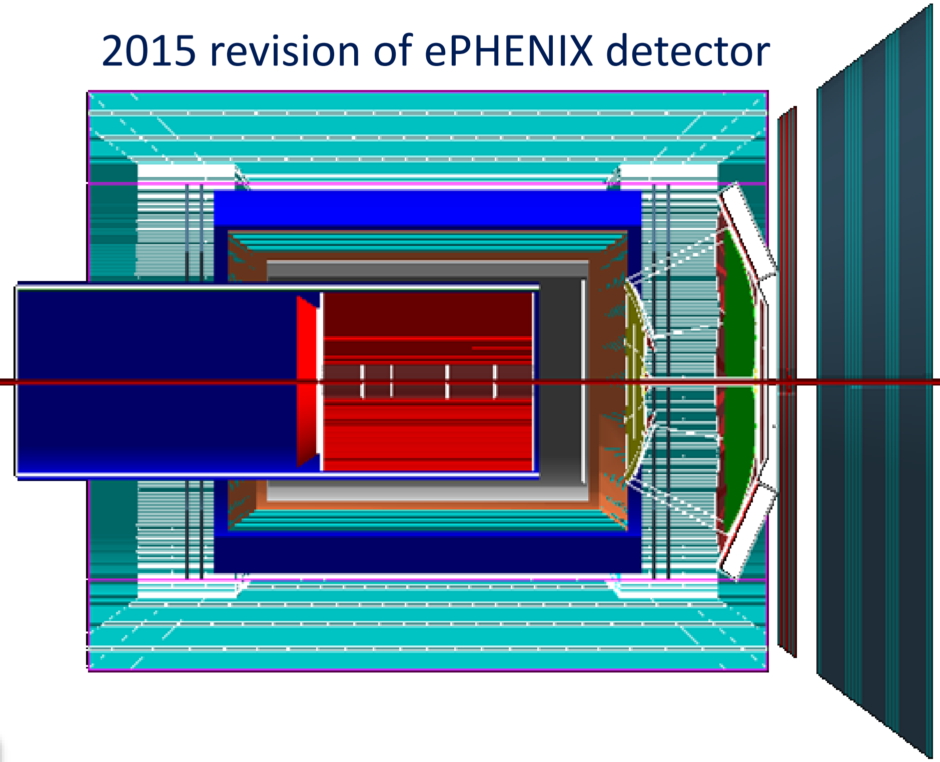
Forward calorimeters and towards EIC

- Calorimeter simulation also extends to forward under the same framework
- fsPHENIX/EIC series of meetings: https://indico.bnl.gov/categoryDisplay.py?categId=93

30 GeV/c pion shower in forward EMCal + HCal



2015 revision of ePHENIX detector



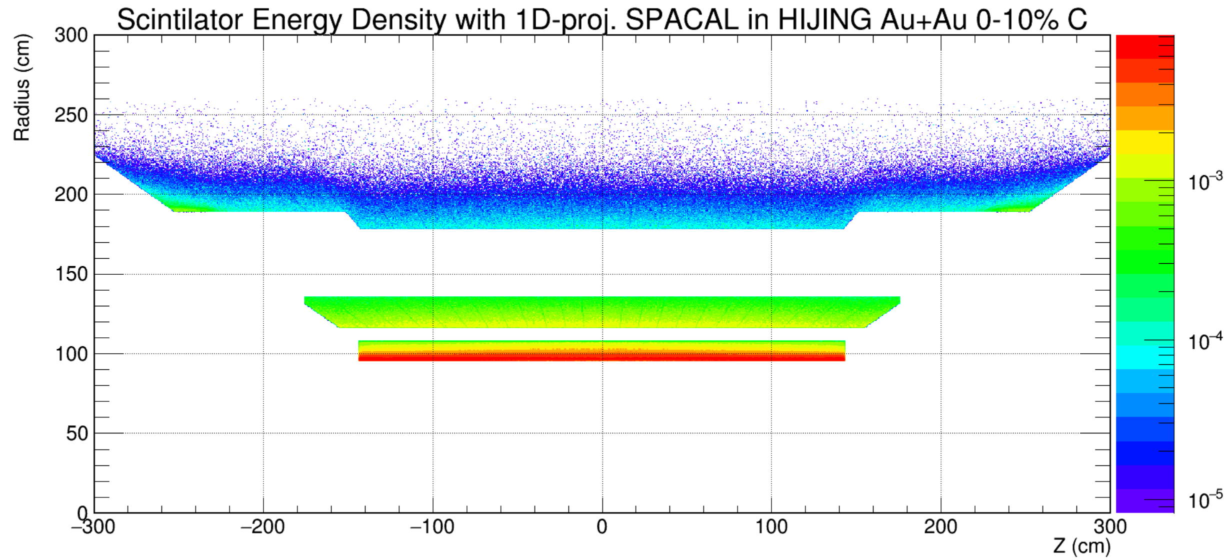
Summary

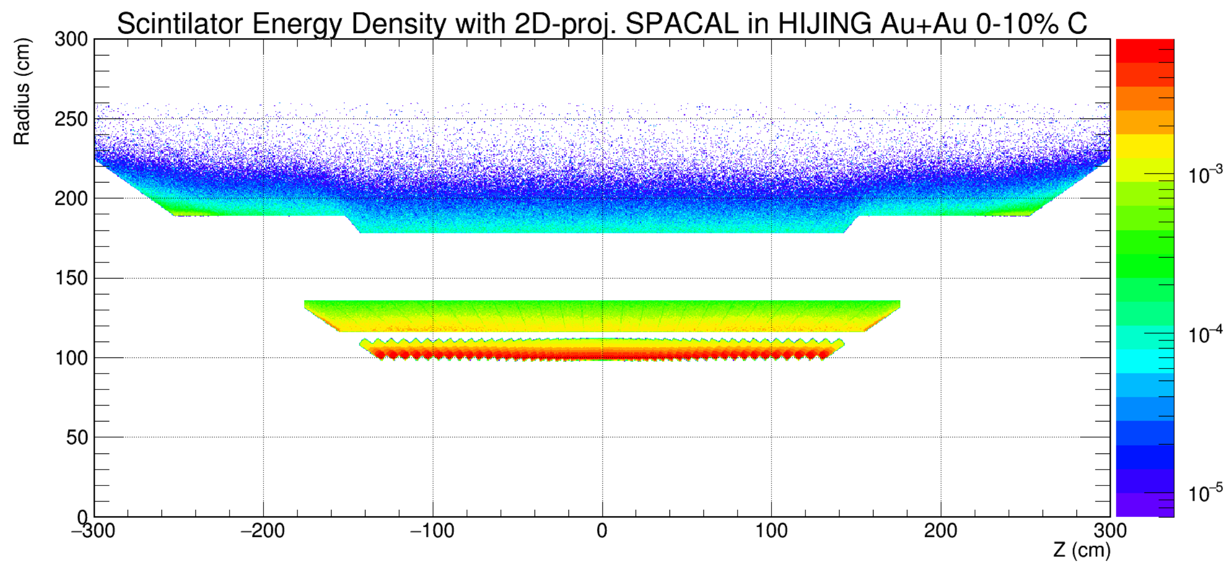
- A detailed model of the sPHENIX calorimeter has been implemented in GEANT4 and available for design and performance studies
- Reasonable agreement with v1 prototype test beam data
  - Simulation of v2 prototype coming in 2016
- Calorimeter performance achieves the performance goals at current level of simulation
  - Continue work needed to update the physics performance plots as detector design and simulation refines
- Abundant opportunity for new ideas, new contributions

Extra information

Occupancy in Hijing

- Volumetric energy density shown

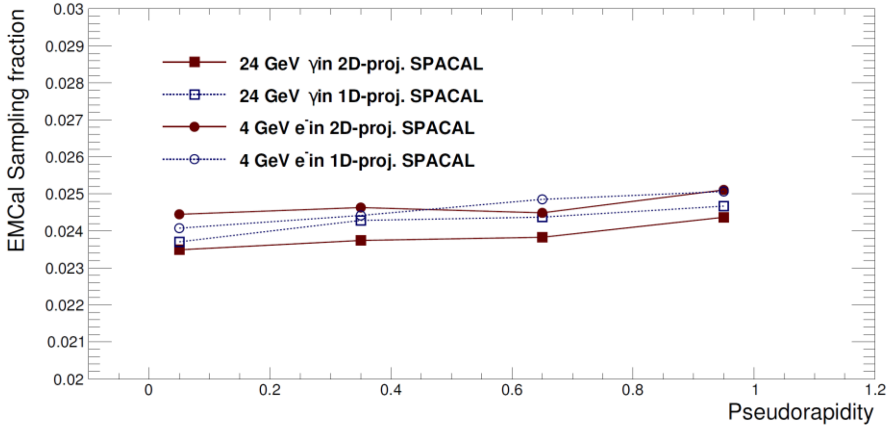


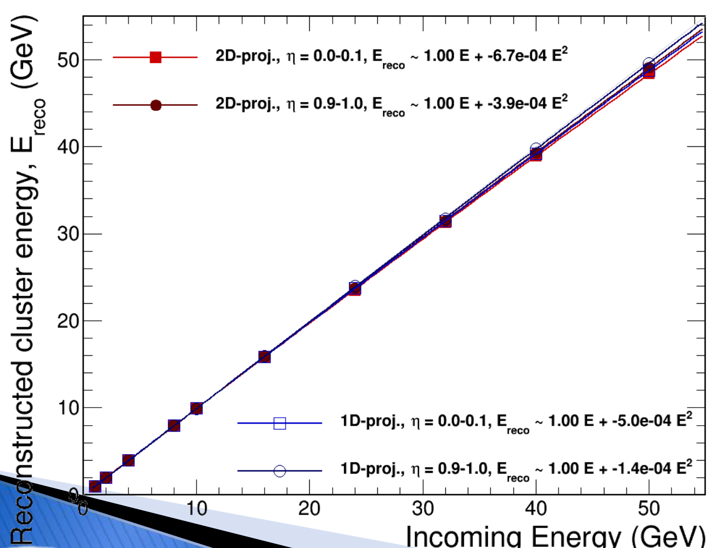


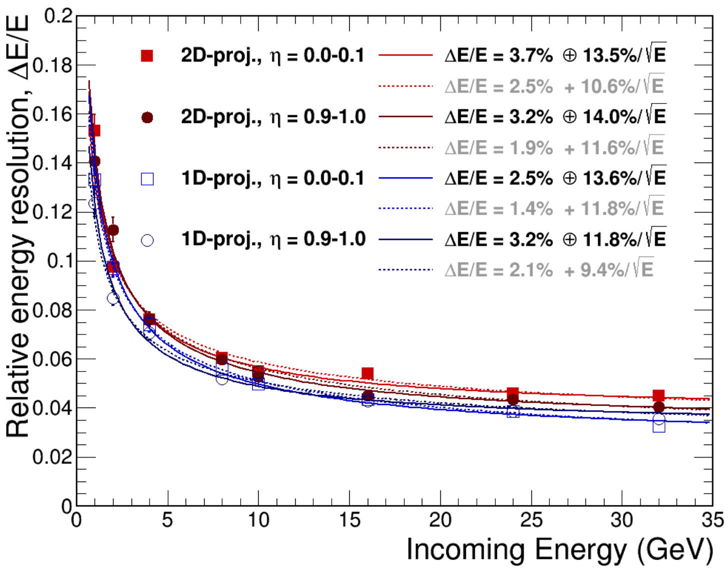
PHENIX

Depth dependency of EMCAL sampling fraction

- Difference between sampling fraction for outer and inner radius is 8% for 2-D projective SPACAL and 4% for 1-D projective version.
- Better presented in energy dependency of sampling fraction and in linearity
- Good linearity observed for both 1-D and 2-D projective designs

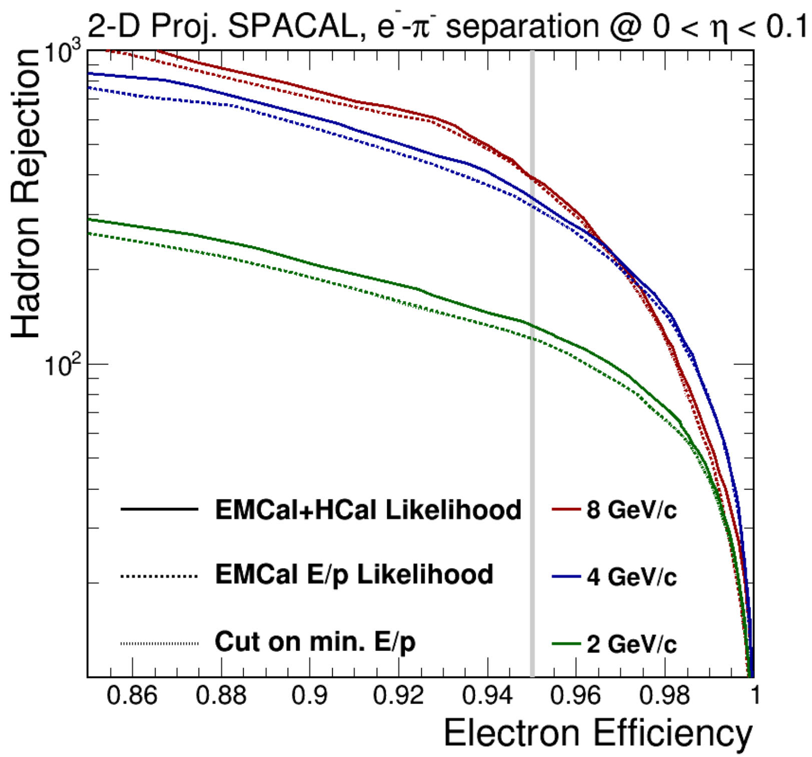


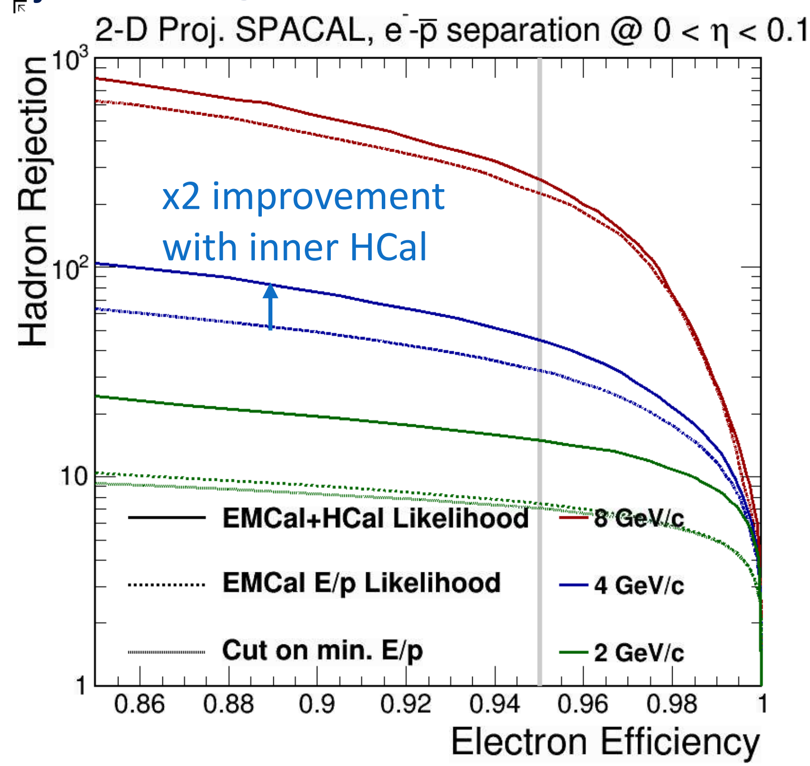




Is inner Hcal useful in e-ID?

Single particle 2/4/8 GeV shower in 2D proj. SPACAL @ eta=0



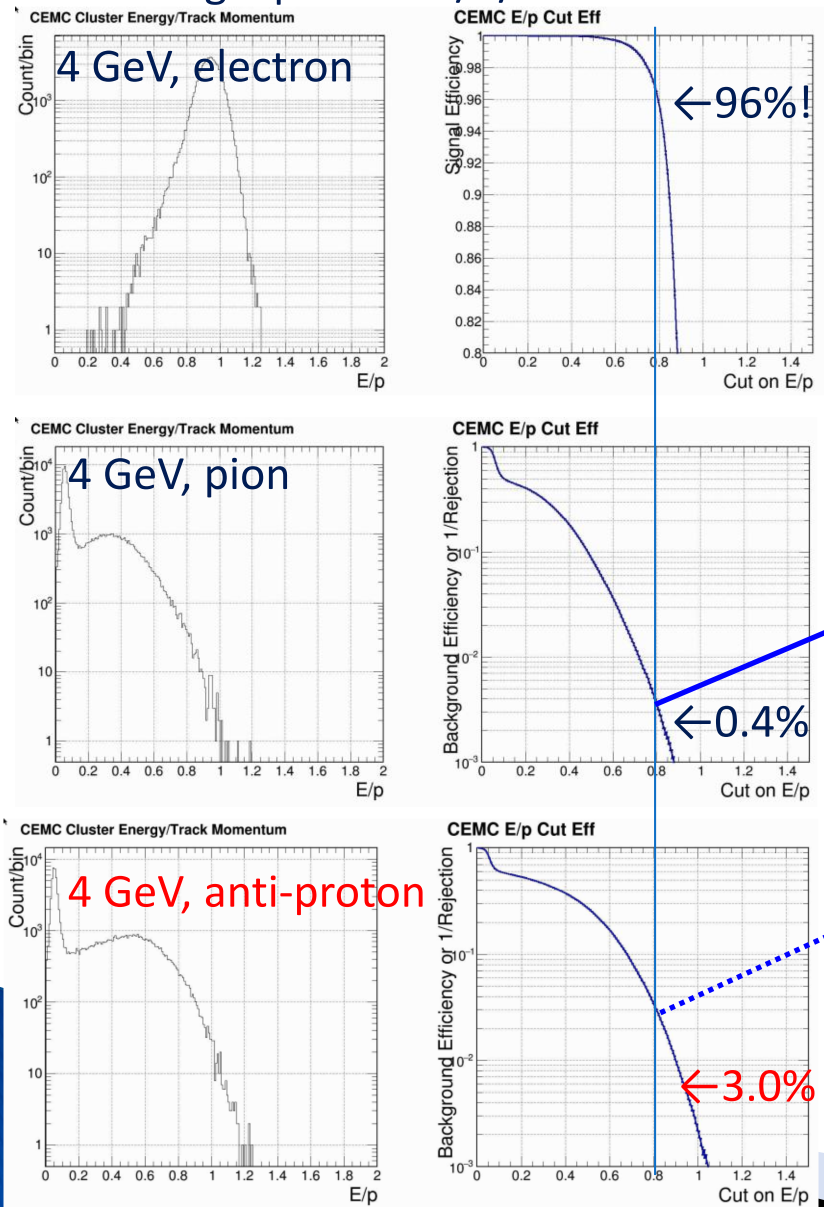


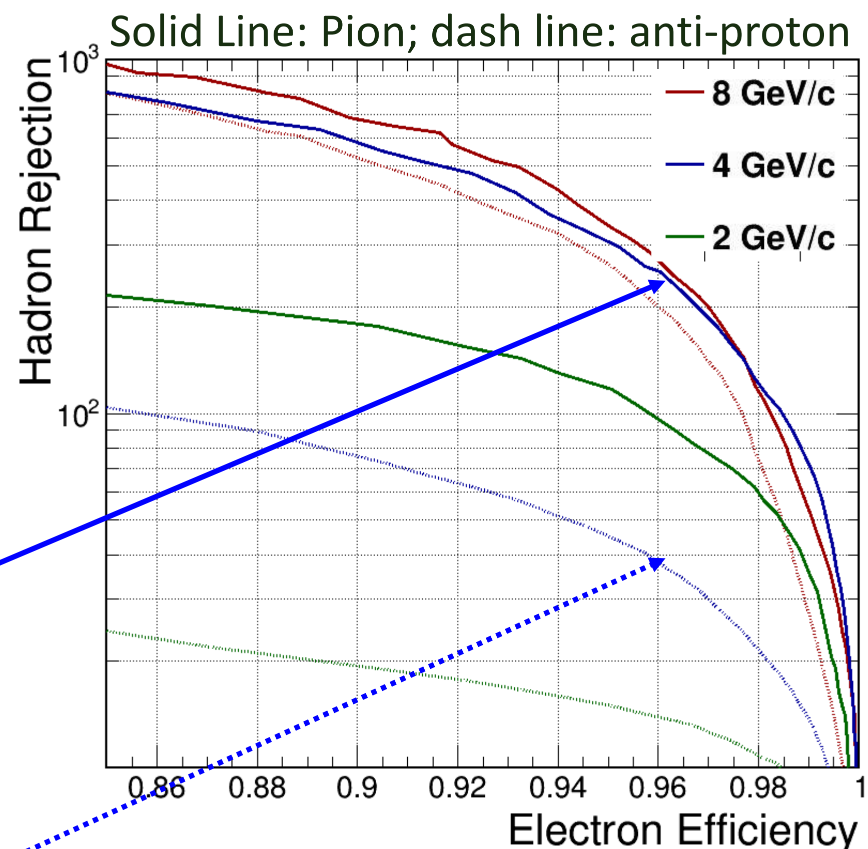
- Pion Rejection curve (pro1.beta5)
- Full digitization (w/ Birk corrections)
Fully implemented 2D SPACAL

- Anti-proton Rejection curve (pro1.beta5)
- Full digitization (w/ Birk corrections)
Fully implemented 2D SPACAL

Performance : electron-ID in p+p

Single particle 2/4/8 GeV shower in 2D proj. SPACAL @ eta=0





- Hadron Rejection curve (pro1.beta5)
- EMCal+HCal + 2D Likelihood PID
  Full digitization (w/ Birk corrections)
  Fully implemented 2D SPACAL

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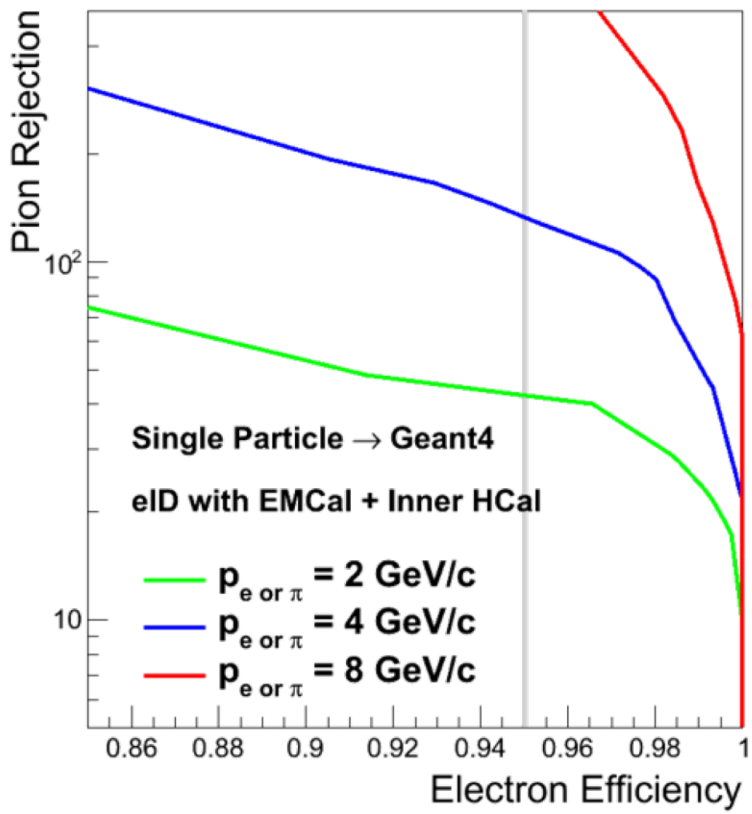
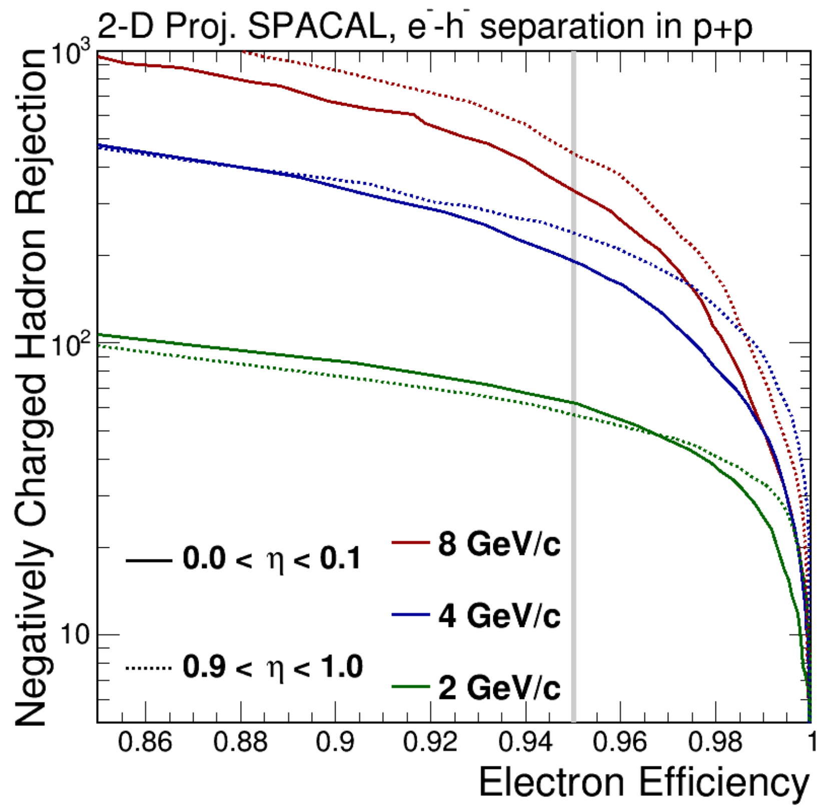
Performance : electron-ID in p+p

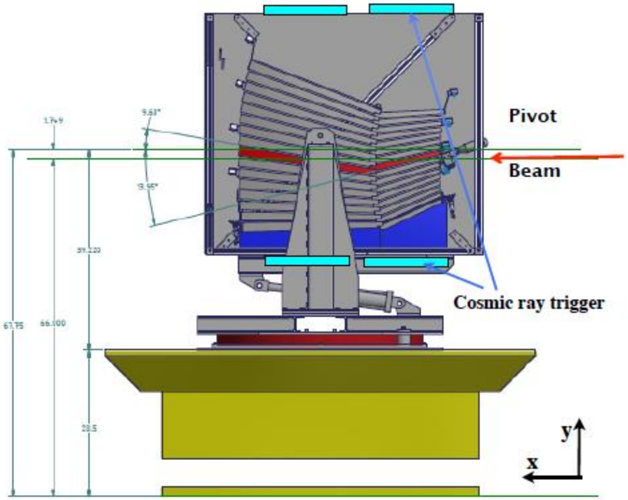


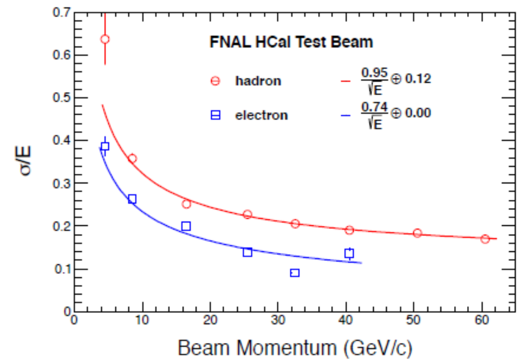


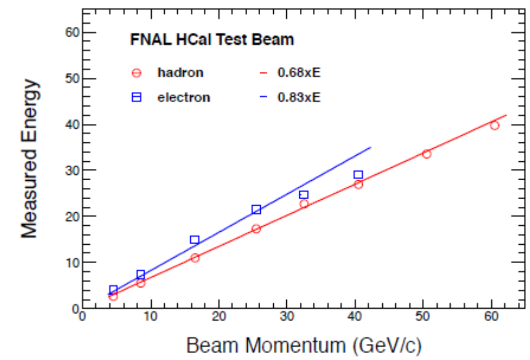
- Baseline performance
- Sum all scintillator energy
  1D SPACAL material cut into 2D SPACAL towers

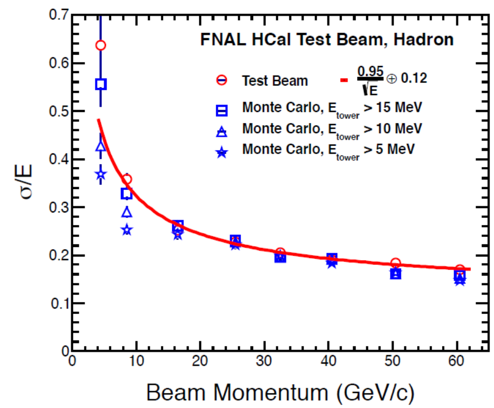
- Updated studies (Preliminary)
- Sum all hadron taking account of hadron ratio
  Full digitization (w/ Birk corrections)
  Fully implemented 2D SPACAL

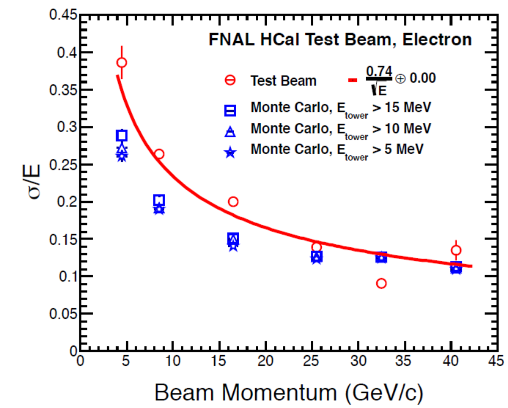
Hcal Test beam 2014 FNAL

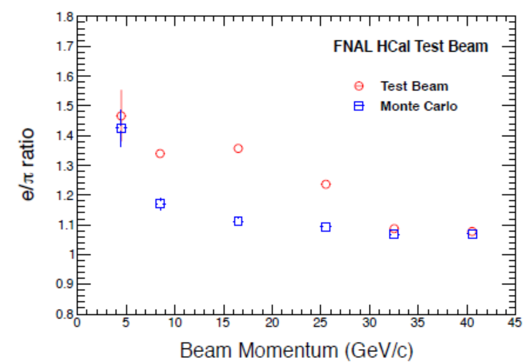




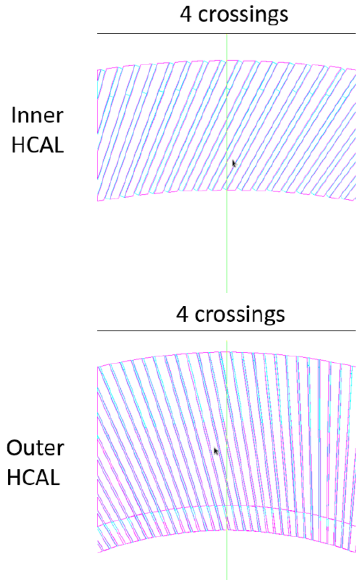


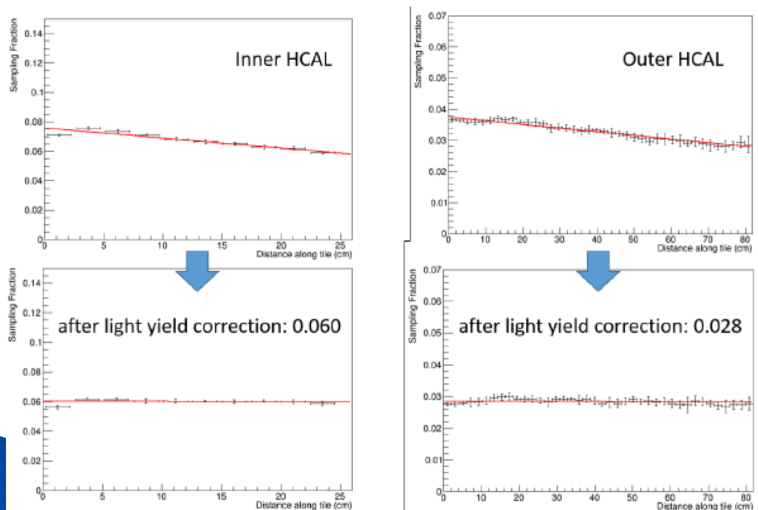




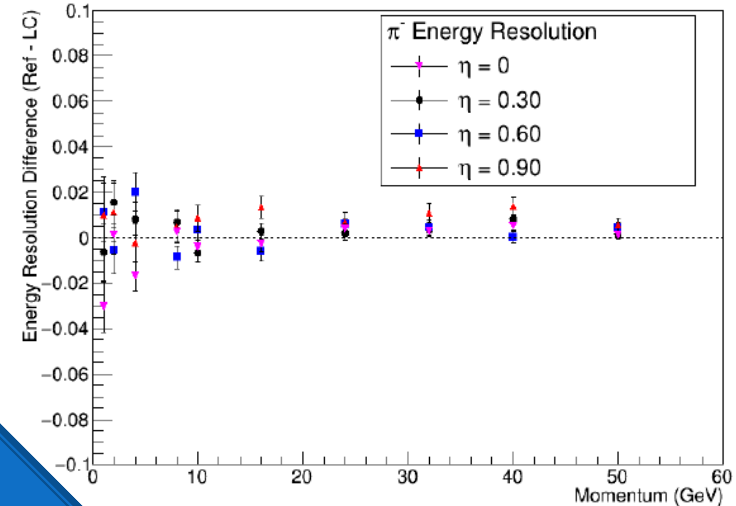


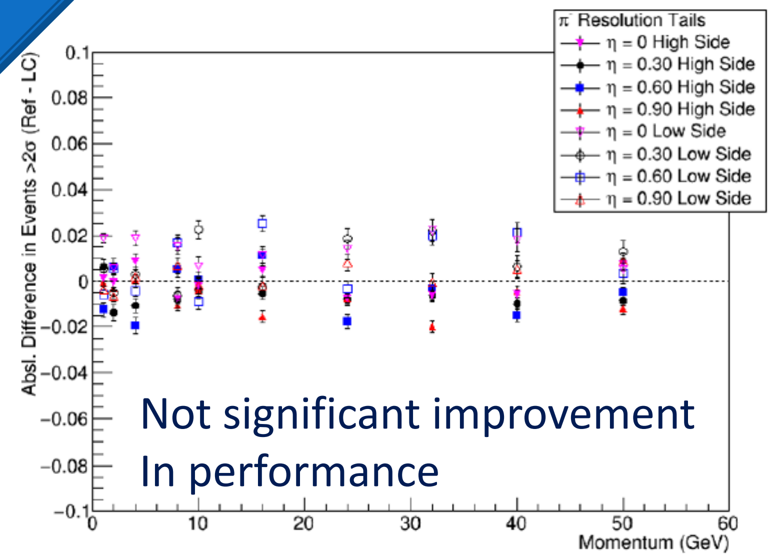
Hcal tile details





Correct for depth dep. Sampling fraction





Not significant improvement
In performance

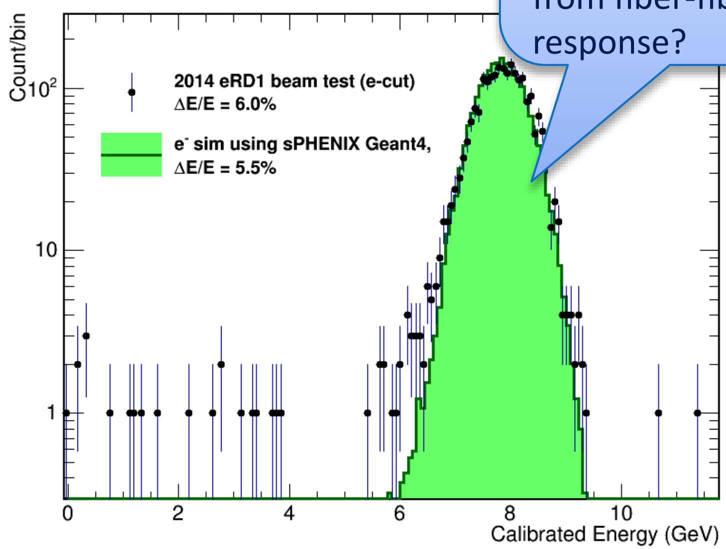
Software tools

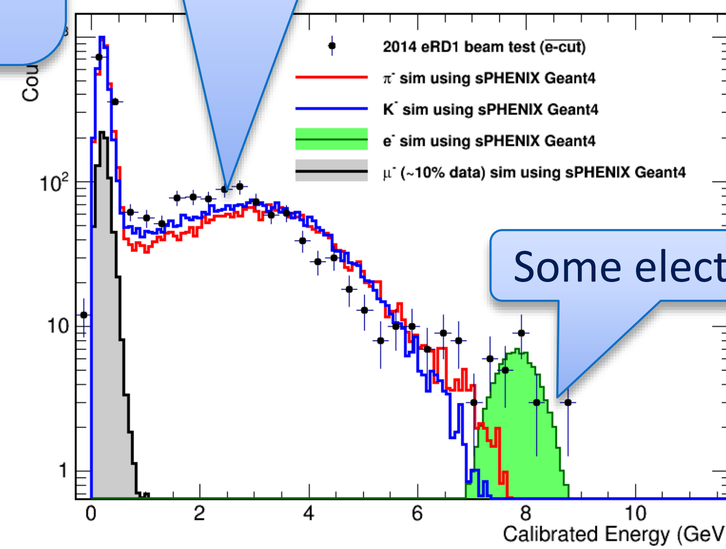
- Software: in analysis repository
  - https://github.com/sPHENIX-Collaboration/analysis/tree/master/EMCal-analysis
  - Analysis module : EMCal-analysis/EMCalAna
  - Plot macros: EMCal-analysis/macro
- Mike's evaluator tool are very useful in trace between truth and reco track/towers
- Fun4All analysis module to build my ntuple of emcal focused analysis

Test beam comparison:
8 GeV beams shower in Geant4 VS data

Very good matching in line shape.
Data: slightly more fluctuation (<10% rel.) from fiber-fiber response?

Less response in data?
Proton component?

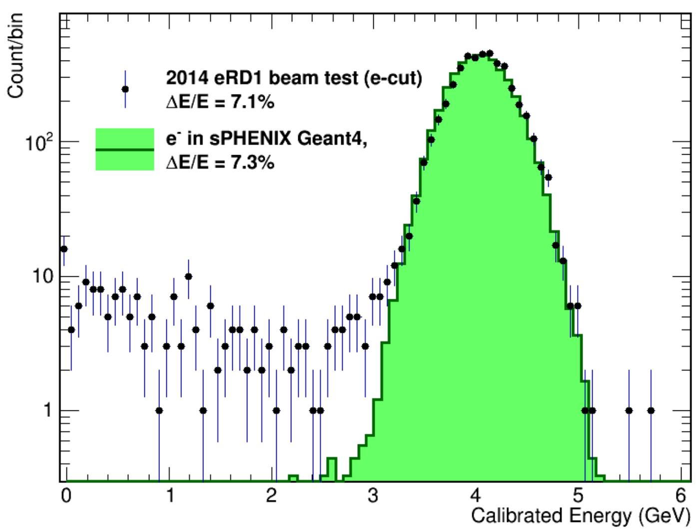


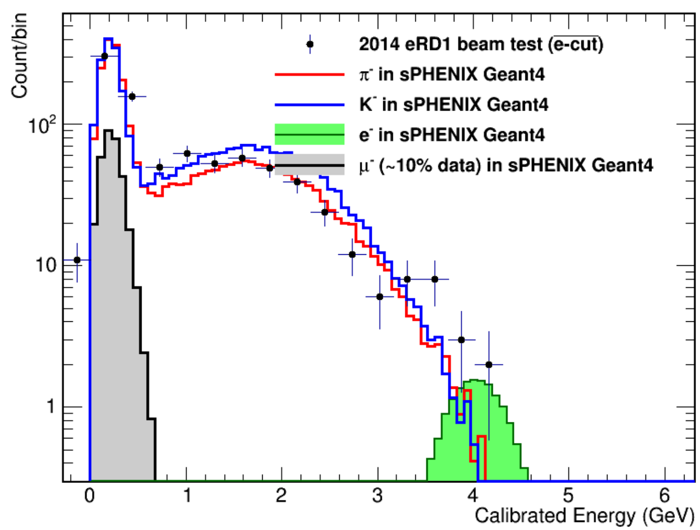


Some electron left

Full Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (2ADC), photon fluctuation (500e/GeV), NO fiber/fiber response

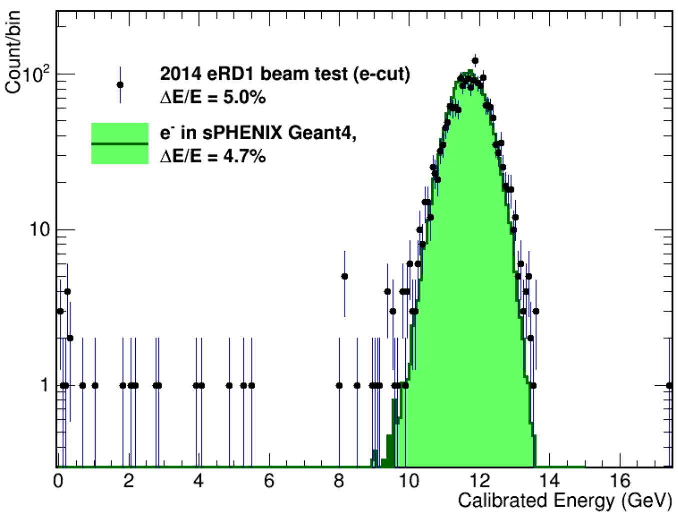
Test beam comparison:
4.12 GeV/c beams shower in Geant4 VS data

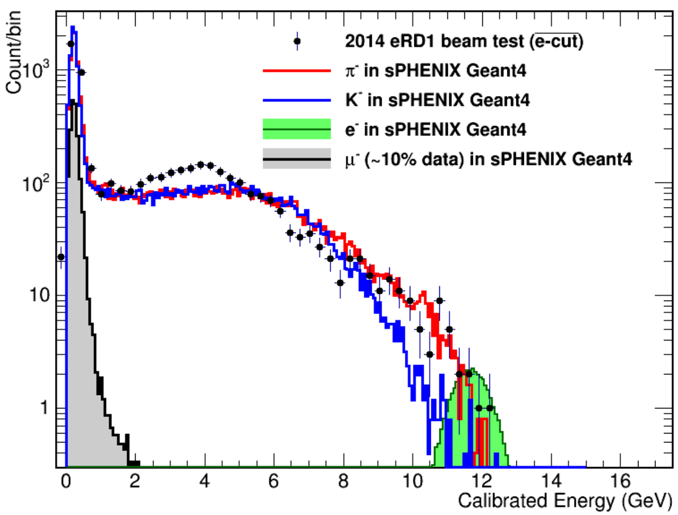




Full Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (2ADC), photon fluctuation (500e/GeV), NO fiber/fiber response

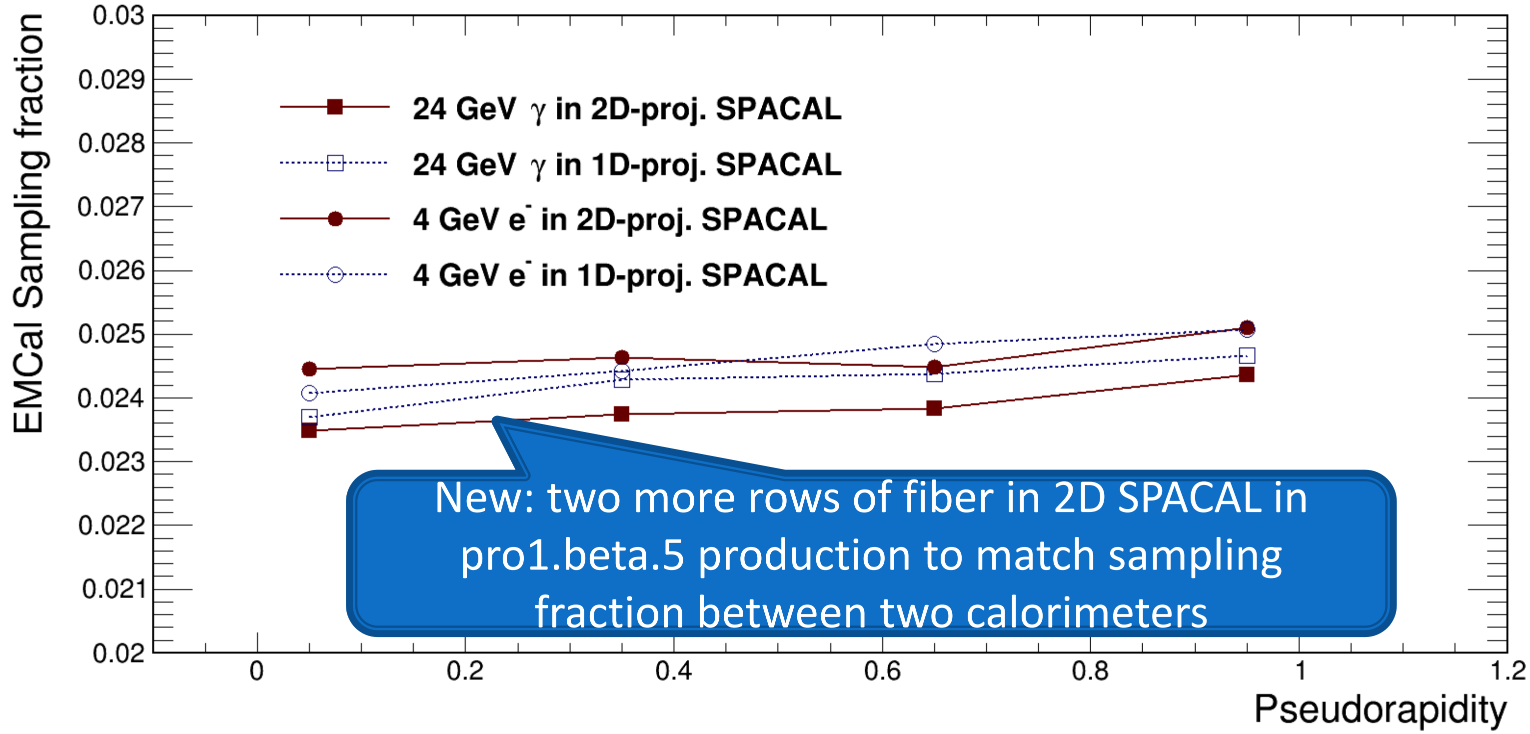
Test beam comparison:
12 GeV/c beams shower in Geant4 VS data





Full Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (2ADC), photon fluctuation (500e/GeV), NO fiber/fiber response

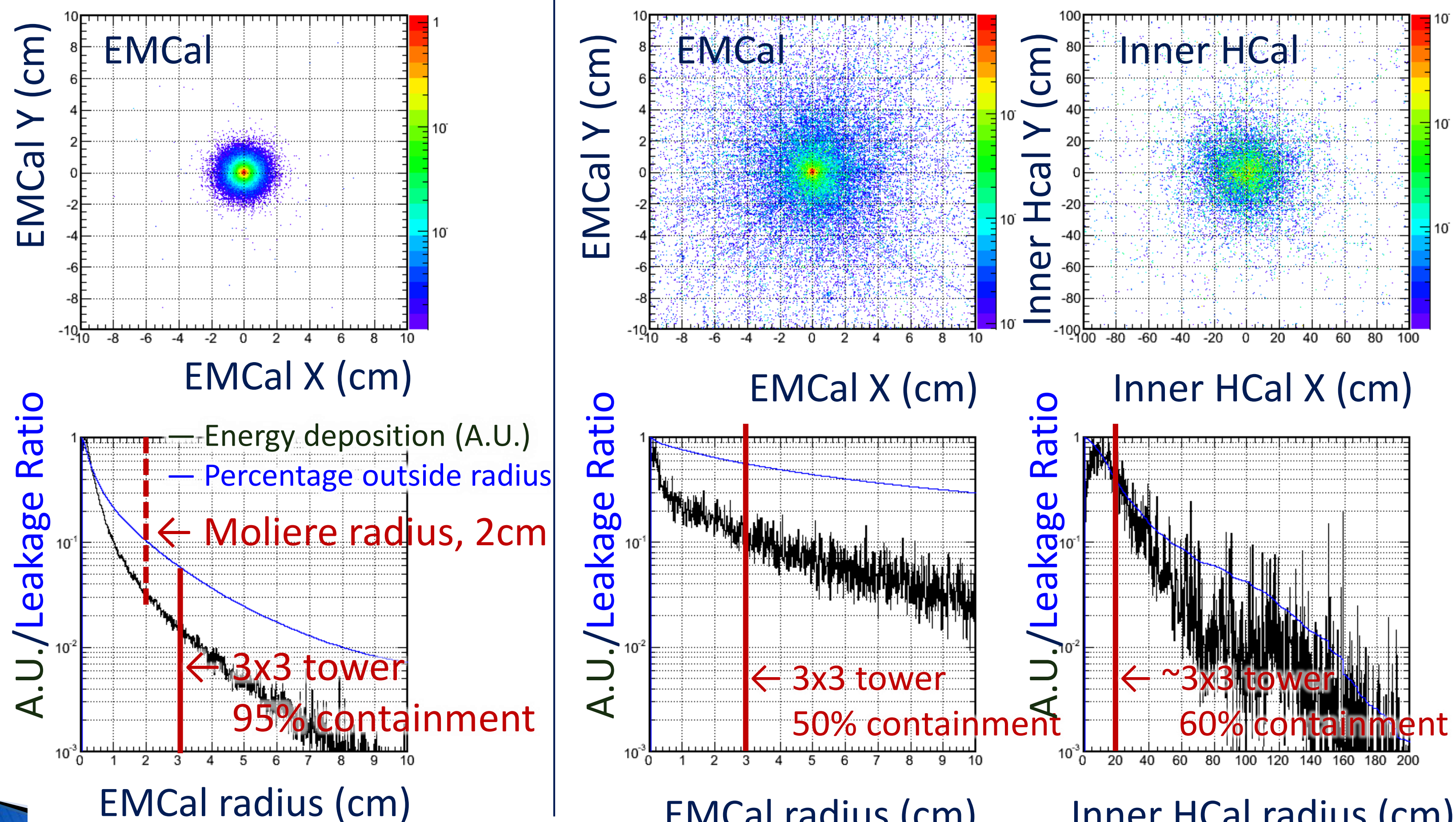
Sampling Fraction



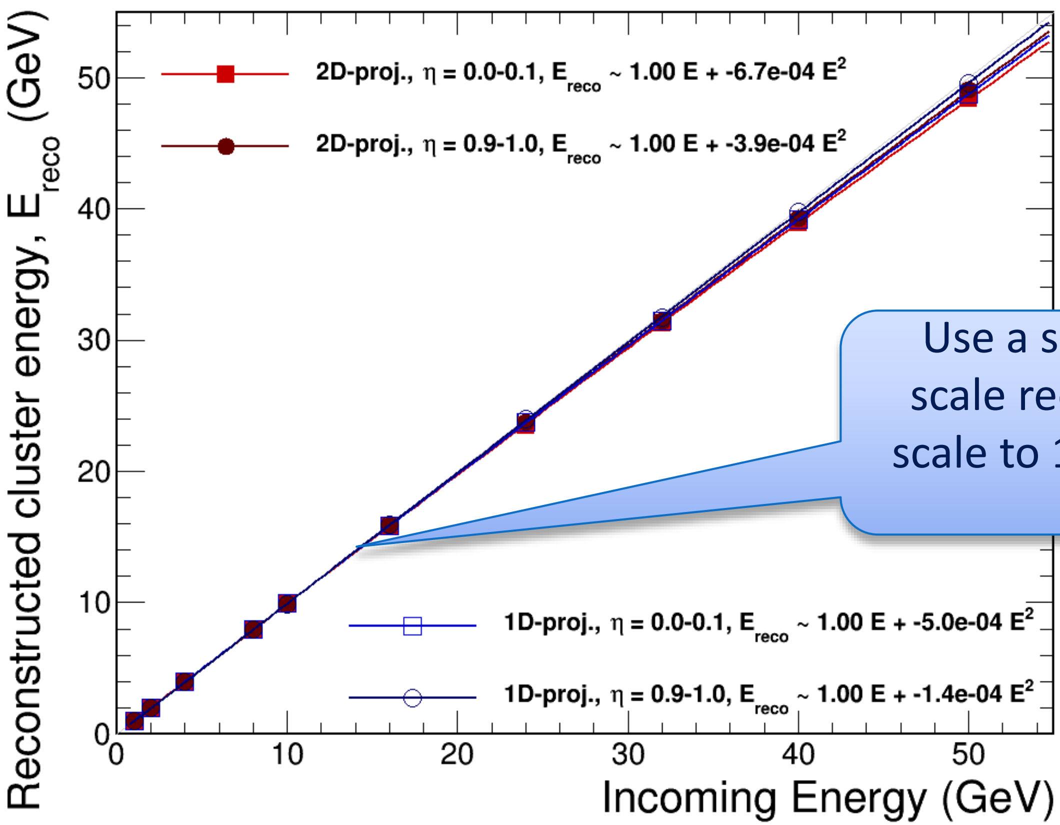
/direct/phenix+sim02/phnxreco/ePHENIX/jinhuang/sPHENIX_work/single_particle/DrawEcal_DrawSF.pdf

Lateral extension of shower

4 GeV Electrons | **4 GeV Pions**, that **passed E/p electron-ID cut**



Linearality – double checking



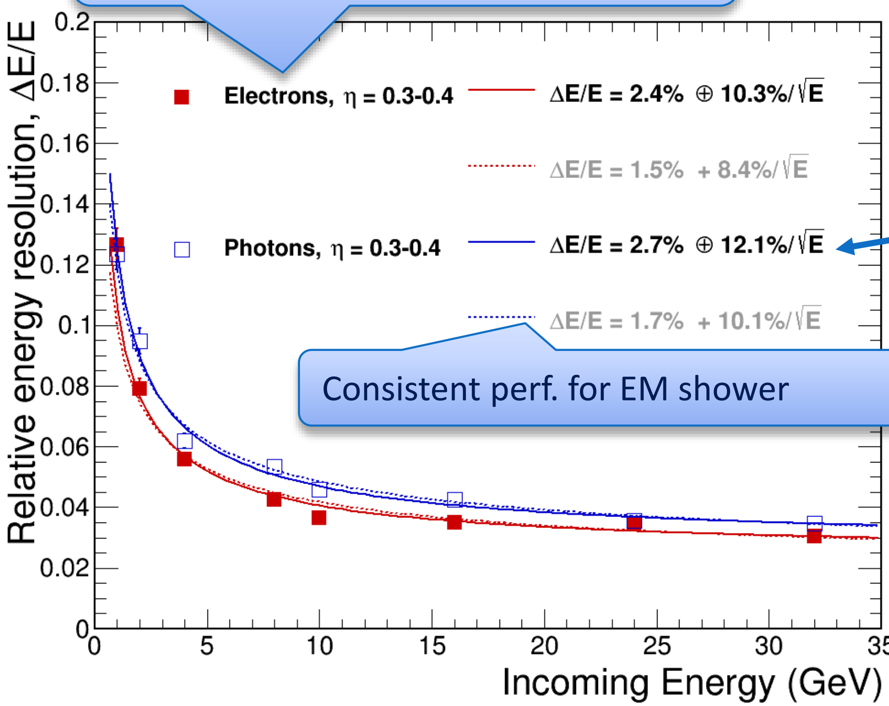
Use a scale correction to scale reconstructed linear scale to 1 individual at each eta region

Energy resolution VS test beam

Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (8pe), photon fluctuation (500pe/GeV), Zero sup (16pe/32MeV), Graph Clusterizer

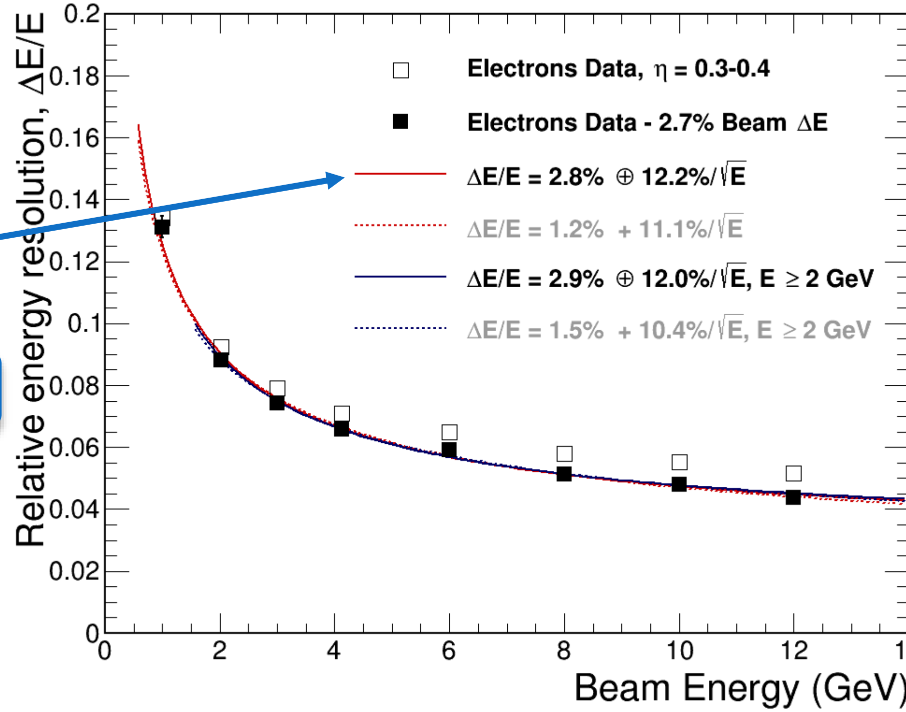
sPHENIX simulation,
1D projective EMCal only, full B

1GeV electron is B-bended by 0.45 rad
→ higher SF. and performance



Consistent perf. for EM shower

EIC RD1 study
FermiLab beam tests, 1D projective EMCal



Note difference in range of X-axis

Energy resolution inspections

Simulated on SPACAL without VTX and in full magnetic field

- 1GeV electron is bended by 0.45 rad → performance ~ photon w/ eta of 0.45 and view higher SF.
- **For EIC, Resolution ~< 12%/√E for electrons after magnetic field bending**
- **For sPHENIX, Resolution ~< 14%/√E for direct photons**

Sampling fluctuation

- 11%/√E for γ
- 9.5%/√E for e^- w/ B

+ readout / clustering

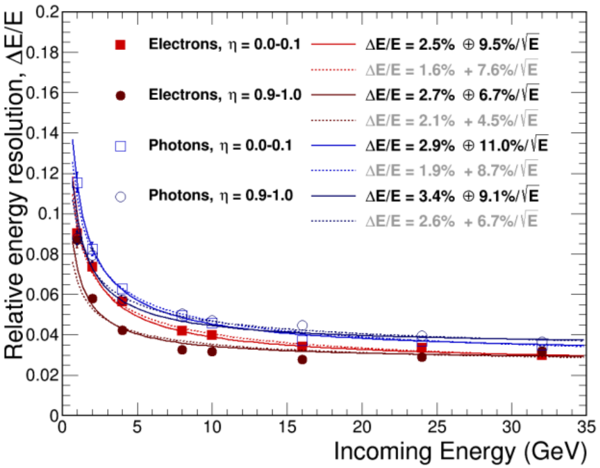
- 13.2%/√E for γ
- 11.9%/√E for e^- w/ B

+ 2D SPACAL

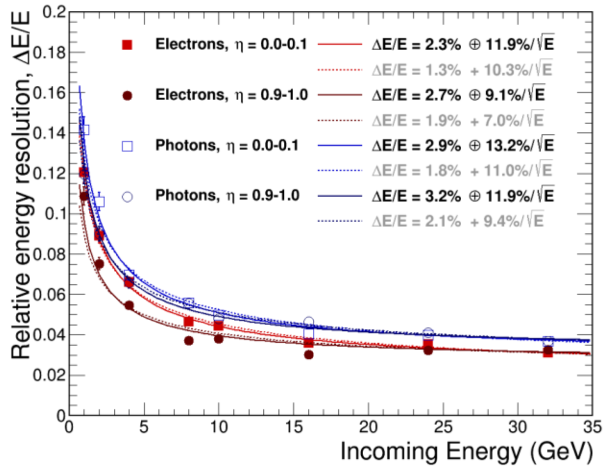
- 13.8%/√E for γ
- 12.2%/√E for e^- w/ B

+ Silicon detector

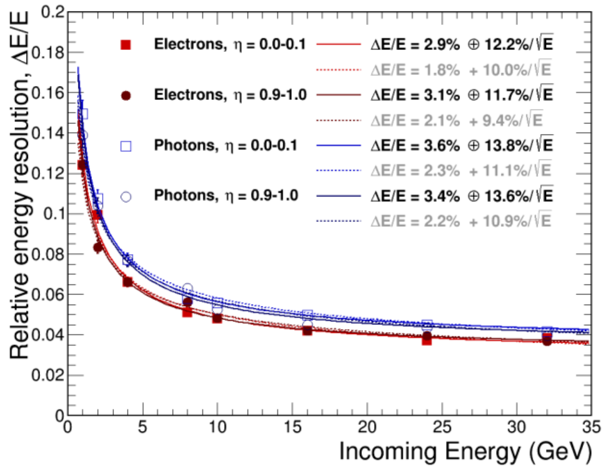
- 13.5%/√E for γ



1D SPACAL, No SVX, Sum all tower
No photo-electron fluctuation/pedestal noise



1D SPACAL, No SVX,
Pedestal noise (2ADC), photon fluctuation (500e/GeV)

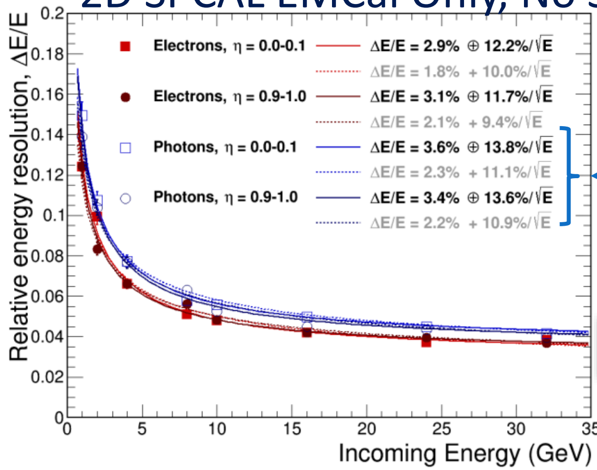


2D SPACAL, No SVX,
Pedestal noise (2ADC), photon fluctuation (500e/GeV)

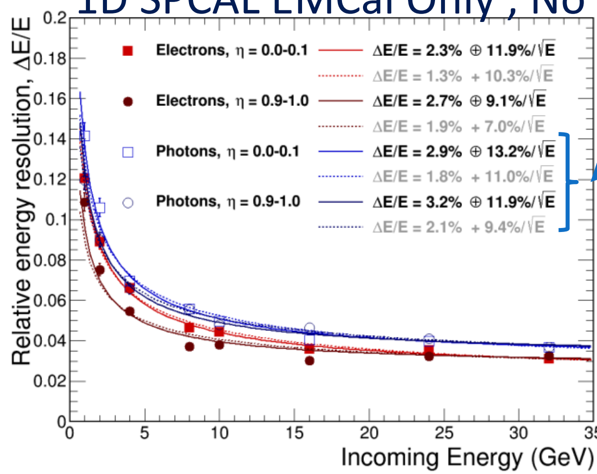
Energy resolution for full detector

Full detector Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (8pe), photon fluctuation (500pe/GeV), Zero sup (16pe), Graph clusterizer

2D SPCAL EMCal Only, No SVX

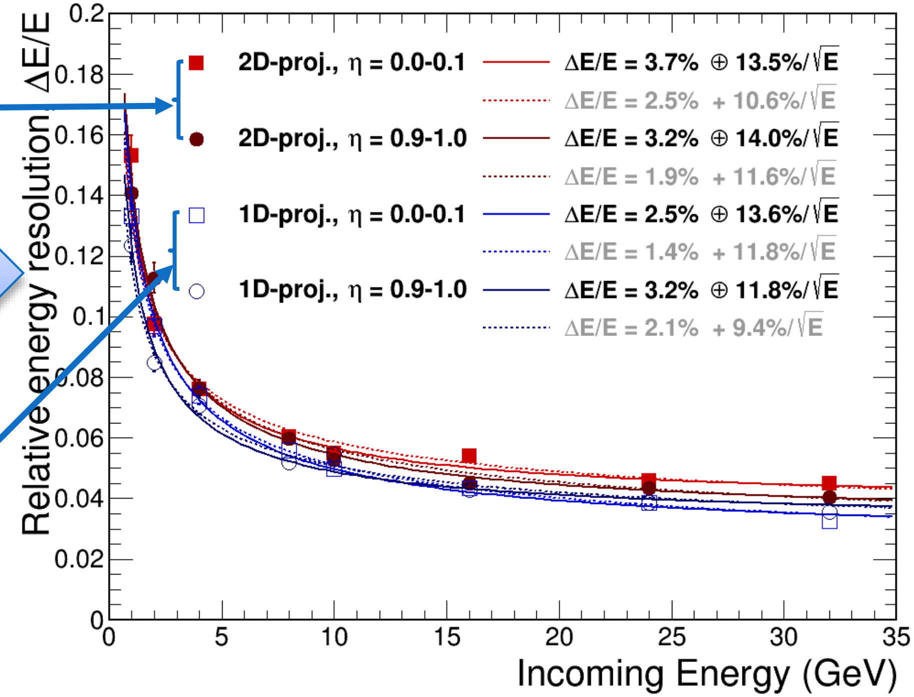


1D SPCAL EMCal Only , No SVX



+SVX

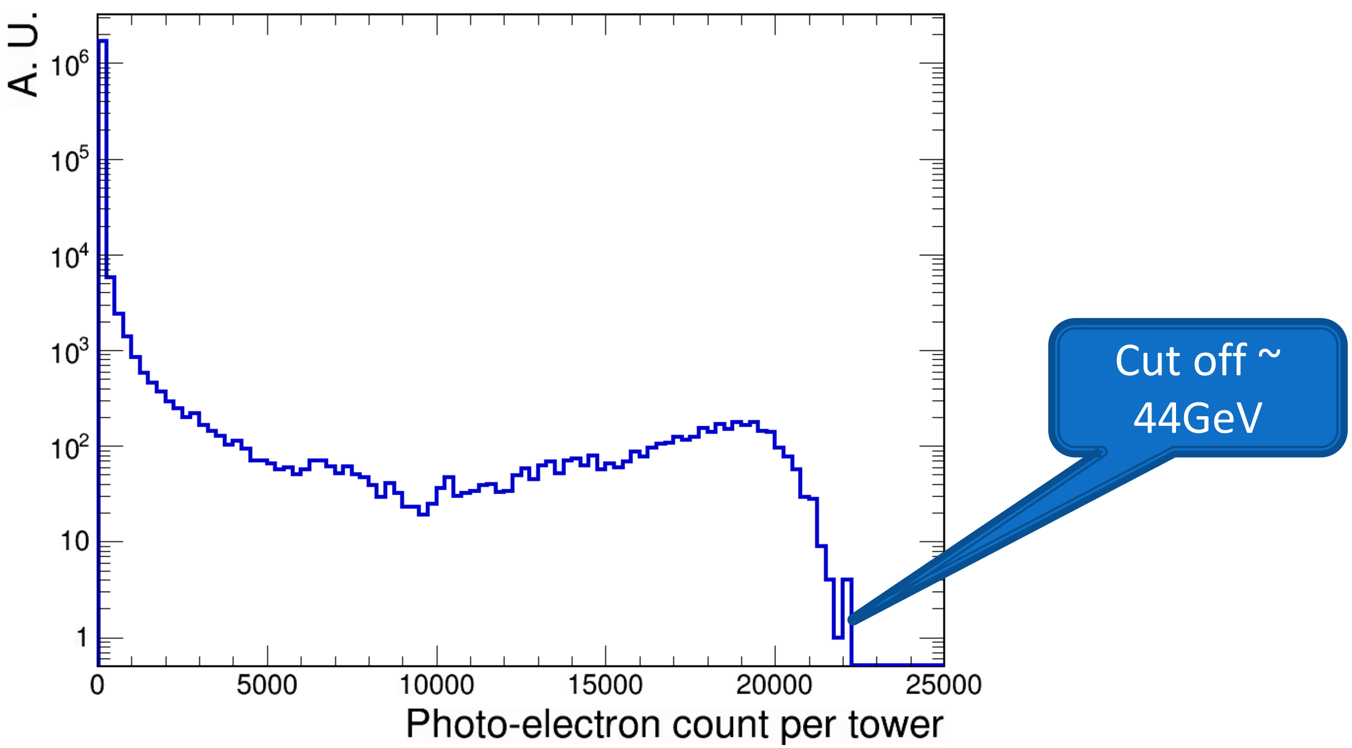
sPHENIX full detector single photon simulation



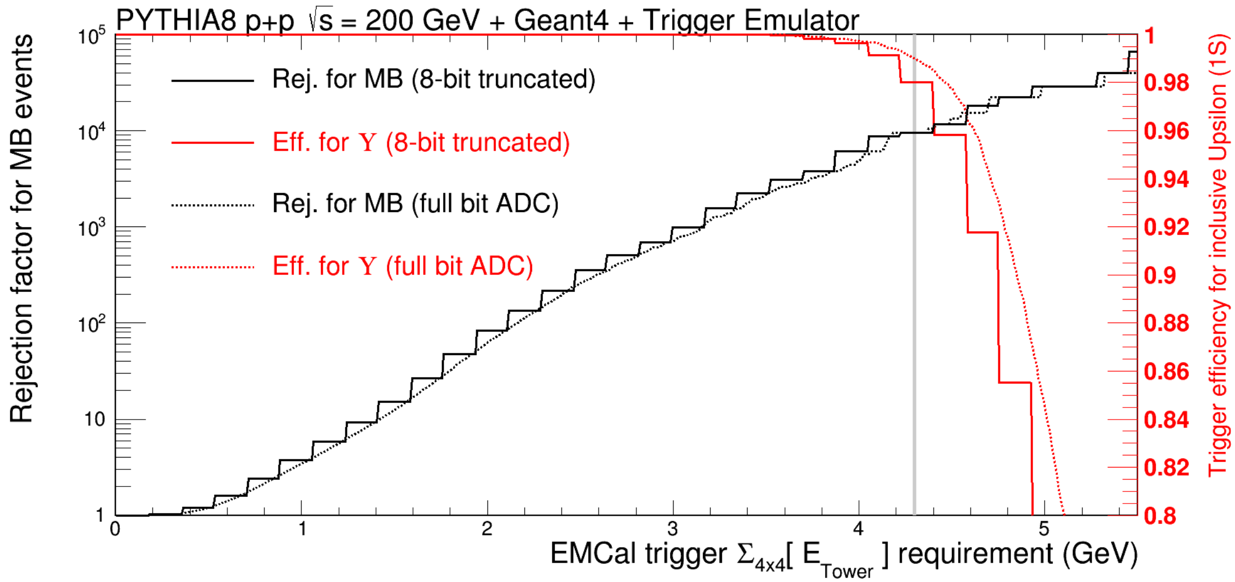
- Photon performance is similar with full detector (+10% X0 SVX before it)

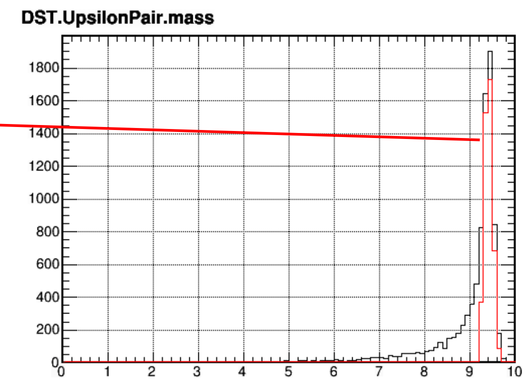
Dynamic range plot

50 GeV photon shower in 2D-projective SPACAL, all eta ranges
Plot photon observed per tower per event,
max ~ 22k photon/tower, pedestal σ~8 photon, range ~ 12bit (max/pedestal 1 σ)



Trigger efficiency – 2D SPACAL





Reconstructed Upsilon (1S) mass (GeV)

Upsilon events required |eta_e|<1, reconstructed |mass – 9.6GeV| < 2 sigma

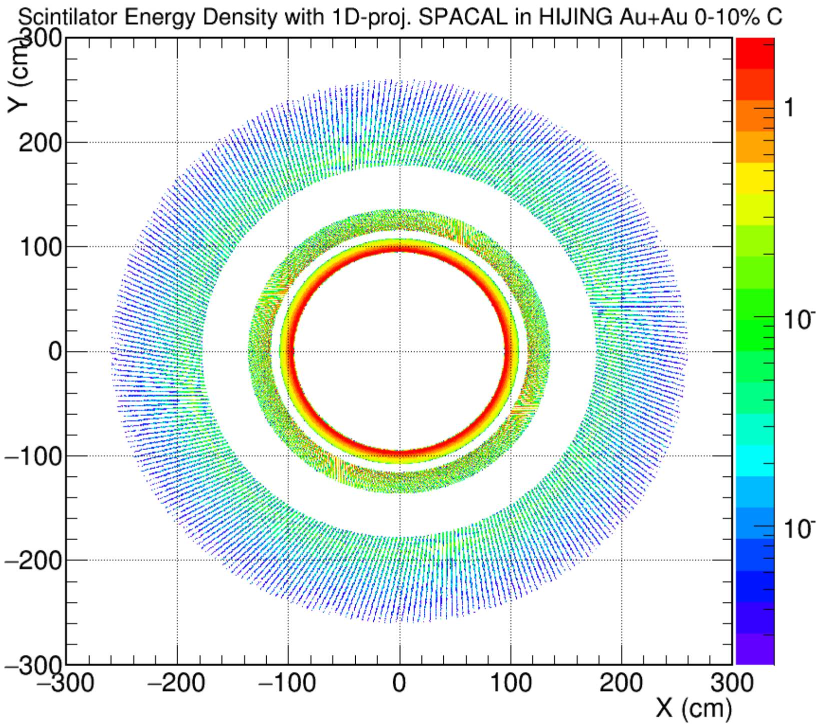
Result: ~10e4 rejection at ~98% efficiency

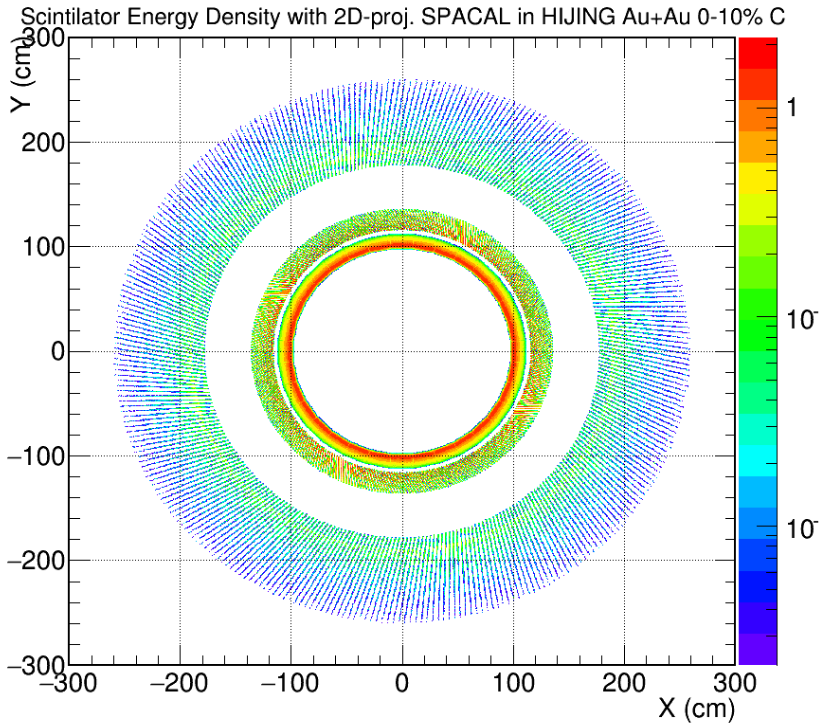
- Tail of Upsilon mass peak excluded for avoiding radiated photon, which are triggered with noticeably lower eff.
- Assumed trigger sum all combination of 4x4 towers, rather than sum of 2x2 → 4x4
- Realistic trigger would use reduced ADC bits, e.g. 8-bit. Performance did not significantly changed.
- 2D SPACAL showed. 1D SPACAL required larger cluster at the forward region

Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (8pe), photon fluctuation (500pe/GeV), Zero sup (16pe/32MeV), Graph Clusterizer

Occupancy in Hijing

2D energy density shown





1D Spacal

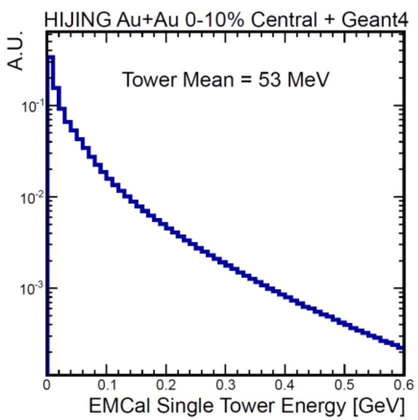
2D Spacal

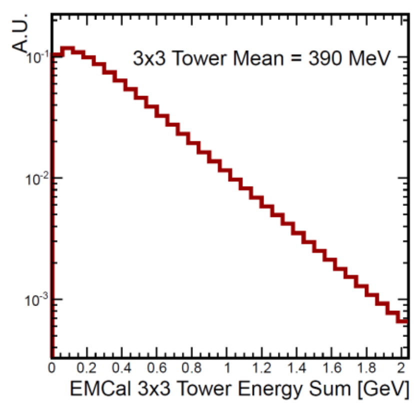
Occupancy – 0-10% Hijing

Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (8pe), photon fluctuation (500pe/GeV), Zero sup (16pe/32MeV), Graph Clusterizer

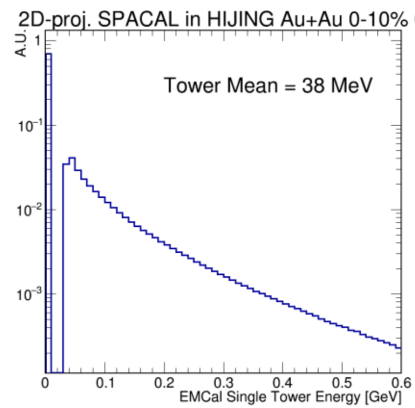
- Note the zero-suppression at 32 MeV.

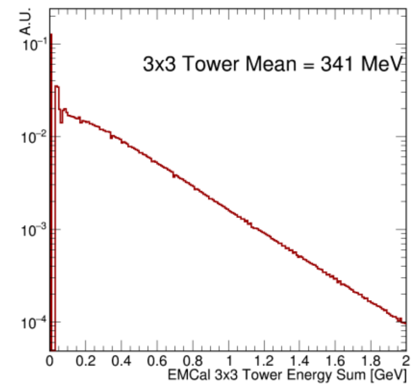
Scientific review (no digitalization, 1D proj.)

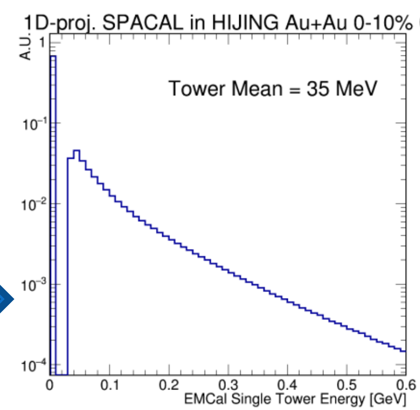


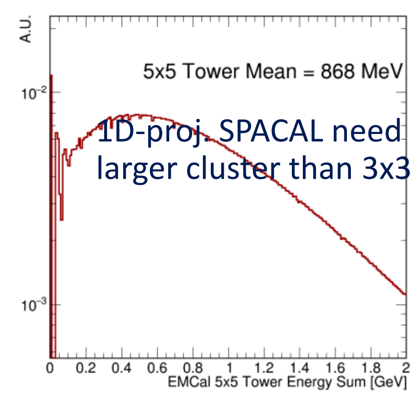


Realistic tower Digitalization



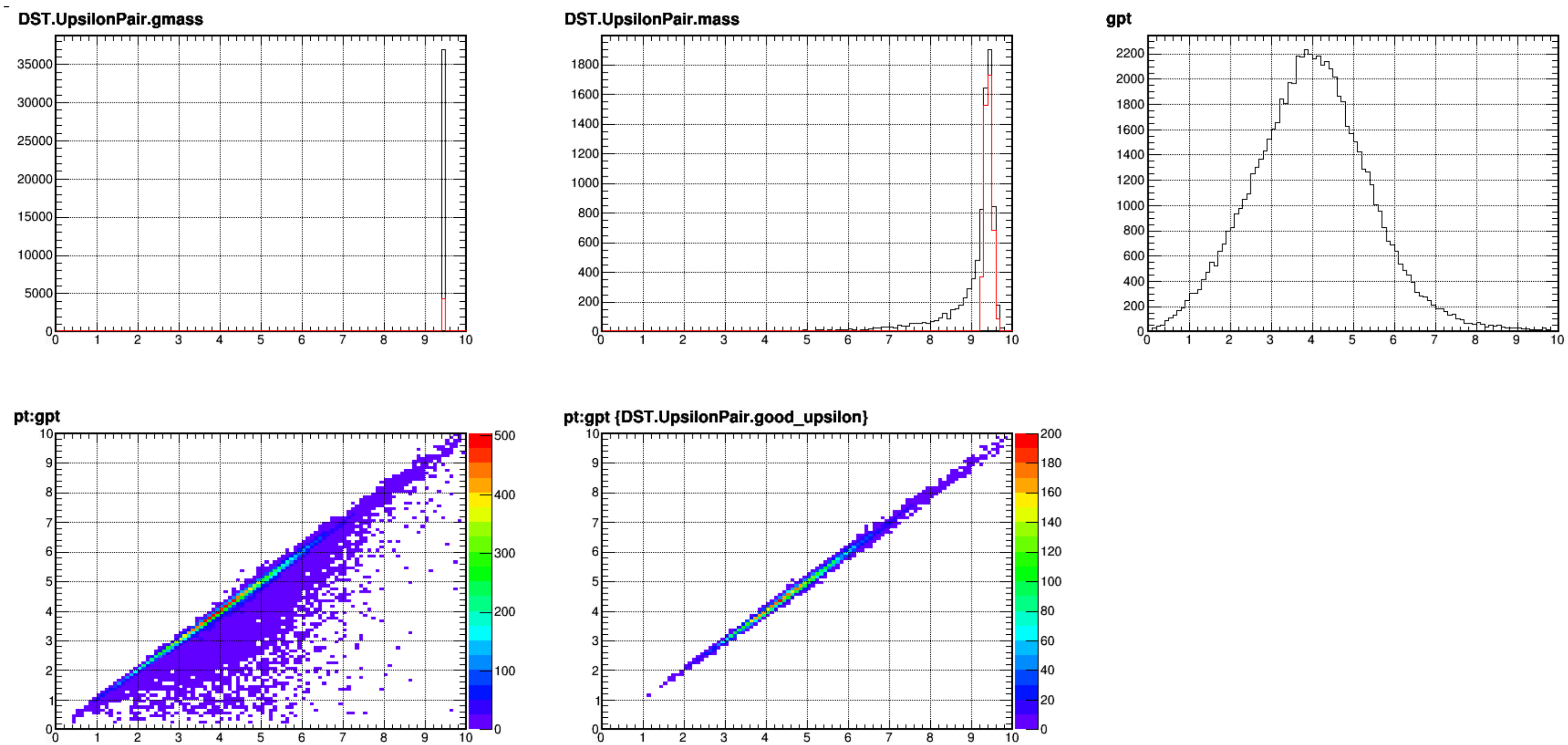






1D-proj. SPACAL need larger cluster than 3x3

Upsilon simulation and selection



Photon resolution [Megan and Stefan]

- PHENIX Clusterizer from Sasha B. survived PHENIX->sPHENIX migration.
  - Promising use of the PHENIX Clusterizer in HI embedded events
- Fit with Gaus
- [0]*exp(-0.5*((x-[1])/[2])**2)

Plots from Megan Connors (GSU)